FELLOWSHIP AWARD UNDER THE COLOMBO PLAN AND MADRAS GOVERNMENT DEPUTATION

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REPORT OF Sri V. P. APPADURAI

Chief Engineer for Electricity

VOLUME 1

INTRODUCTION AND POWER STATIONS

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INTRODUCTION AND POWER STATIONS.

A. INTRODUCTION.

1. The Shawinigan Water and Power Company, Limited, of Canada.

Canada abounds in large rivers and streams which play an important role in the industrial and electrical development of this country. The commercial water power resources are estimated at 52,000,000 h.p. with over 10,931,000 h.p. or about 21 per cent so far utilized. The province of Quebec is richer in water power than any of the other provinces of Canada. It has 17,000,000 h.p. available of which only 6,000,000 h.p. or 35 per cent has so far been developed. Quebec's yearly production of electricity is claimed to be the highest being 7,000 KWH/capita as compared to 3,500 KWH/capita of Canada as a whole and 2,414 KWH per capita for the United States of America.

All the water power developments in the province of Quebec are located either on the St. Lawrence or any of its tributaries. It was private enterprise that pioneered hydro-electric industry in Quebec and carried it through the difficult formative period. The Provincial Government also helped the movement in the construction of important storage reservoirs in the rivers thus tripling and quadrupling the normal low water discharge of these rivers.

In 1942, the Provincial Government entered the electrical utility field and acquired the electrical system serving the island of Montreal and owned by the Montreal Light, Heat and Power Company and its subsidiary the Beauharnois Power Company. The properties owned by these corporations are now operated by a provincial agency, the Quebec Hydro Commission.

The three most important power systems in the province are the Quebec Hydro Commission, the Shawinigan Water and Power Company, Limited, and the Aluminium Company of Canada and its subsidiary the Saguenay Power Company.

The pioneer centre of Quebec's great power resources is at Shawinigan Falls in the St. Maurice Valley. It is here that the Shawinigan Water and Power Company had its beginning. The two 5,000 h.p. generating units, which were placed in operation at Shawinigan Falls in 1903, were at the time the largest ever manufactured, and the Company's eighty-six mile 50,000 volt transmission line, carrying power from them to Montreal, was the longest and highest voltage transmission line in America. Today the Shawinigan system serves more than 217,000 industrial, domestic, commercial and rural customers in an area of more than 25,000 square miles, extending from Oka to Murray Bay and between the Laurentian shield and the United States border, with a network of lines carrying power to practically all the inhabited areas.

Within this great oval, astride the St. Lawrence River, are found the largest cities and 70 per cent of the population of the Province of Quebec. Shawinigan power lights the homes, shops and streets and is the life-blood of industry in Shawinigan Falls, Grand-mere, Trois Rivieres, Cap de la Madeleine, Sorel, Victoriaville, Thetford Mines, Valleyfield and other important urban and rural centres, while Quebec Power Company distributes electricity in the City of Quebec and surrounding communities. In Montreal and Sherbrooke power is supplied wholesale by the Shawinigan Company for distribution by other power systems. More than 670 communities, in which are located many of Canada's great industrial enterprises, are served by the two systems, while rural lines furnish light and power services to the agricultural districts.

In order to regulate the flow, the Quebec Streams Commission maintains storage dams on some of the principal rivers of the Province and their tributaries. One of the most important of these dams, the Gouin, at the headwaters of the St. Maurice, was constructed by a subsidiary of the Shawinigan Company, in 1917, and forms a lake with an area of over 500 square miles and an average depth of 17 feet. A second, the Mattawin, was built in 1930 by The Shawinigan Engineering Company, Limited. By means of these and other dams, including three on the Manouan River, the prime power capacity of the St. Maurice Valley has been tripled.

At Shawinigan Falls, the initial development of The Shawinigan Water and Power Company was begun in 1899. During the next four years, excavation and construction work was carried out and by 1903 the first two units were installed in the original power house. In subsequent years, many improvements and additions have been made and the latest development brings the installed capacity to 489,900 h.p.

In the three power houses at Shawinigan Falls can be seen the progressive evolution of hydraulic and electrical generating equipment over half a century. From the original two units of 5,000 h.p. each, which are still in operation, to the three 65,000 h.p. units in the latest power house, the successive steps in design and capacity of hydro electric generating units can be clearly traced. These installations are a Mecca, visited by members of the engineering profession from all parts of the world.

Over a hundred miles upstream from the City of Shawinigan Falls, stands the remote but modern power house of Rapide Blanc, now operating with five units of 40,000 h.p. each. This development, begun in 1931, will eventually have a total capacity of 240,000 h.p. At present the most northerly plant of the Shawinigan system, this is the first and central plant of seven, planned to harness the upper reaches of the St. Maurice River.

The second of these seven, the 222,500 h.p. La Tuque development of the St. Maurice Power Corporation, jointly owned by The Shawinigan Water and Power Company and Brown Corporation, was brought into operation in 1940. An additional unit, provision for which has already been made, will bring the eventual capacity to 267,000 h.p. The plant is operated as part of Shawinigan's St. Maurice Valley system and power is purchased by the Company under long-term contract.

Other sites yet to be developed on the Upper St. Maurice are Rapide Allard, Rapide du Lievre, Rapide des Coeurs, and Rapide Sans Nom, which together will have an ultimate capacity of over 1,000,000 h.p.

The map and profile, shown in sketch PS1 give the location of the various power plants and undeveloped sites on the St. Maurice River.

Thirty miles above the mouth of the St. Maurice, at the gateway to the pulpwood stands of Northern Quebec, is the 201,000 h.p. Grand'mere development. In 1924, the 172,000 h.p. plant at La Gabelle, seven miles below Shawinigan Falls, was brought into operation. The Company also has power houses at St. Narcisse on the Batiscan, at St. Alban on the Ste. Anne de la Parade and at Disraeli on the St. Francis, with a combined capacity of 30,200 h.p.

Quebec Power Company owns and operates the 24,000 h.p. development at Seven Falls on the Ste. Anne (de Beaupre) River near St. Fereol. This plant, which was acquired in 1925, makes use of a drop of 410 feet, the highest used by any power plant in Eastern Canada. The Company also operates power houses at Montmoreney Falls, Natural Steps, Chaudiere, St. Gabriel and St. Raphael, with a combined capacity of 17,725 h.p.

THE SHAWINIGAN WATER AND POWER COMPANY

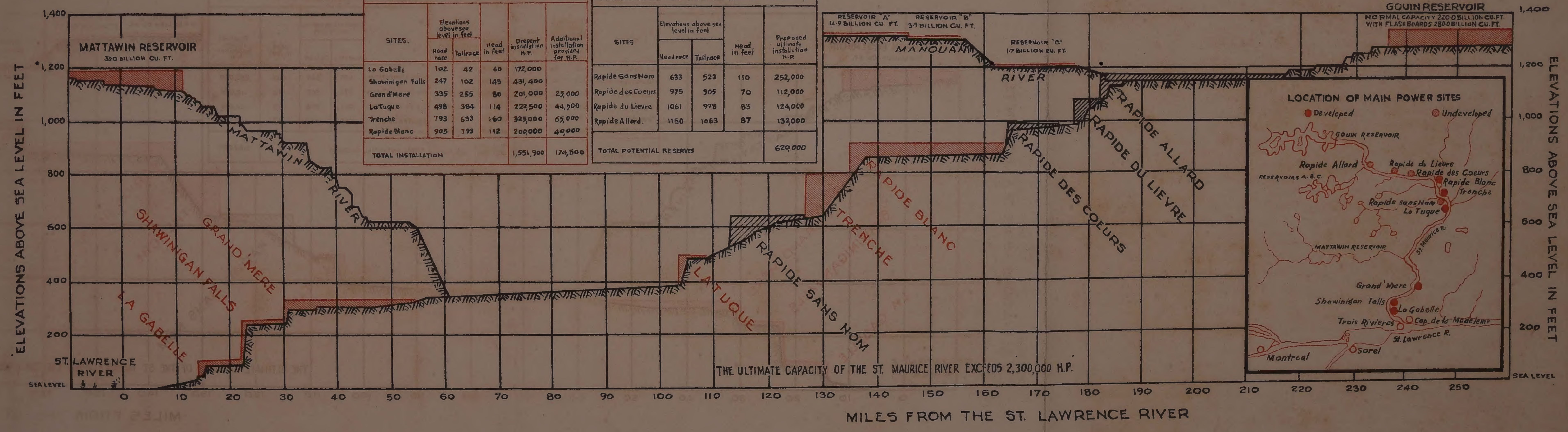
DIAGRAMMATIC PROFILE OF THE ST. MAURICE RIVER, QUEBEC.

EXISTING POWER DEVELOPMENTS (Shown in Red)

SITES.	Elevations above sea level in feet: Head race	Tailrace	Head in feet	Present installation H.P.	Additional installation provided for H.P.
La Gabelle	102	42	60	172,000	
Shawinigan Falls	247	102	145	431,400	
Grand'Mere	335	255	80	201,000	25,000
La Tuque	498	384	114	222,500	44,500
Trenche	793	633	160	325,000	65,000
Rapide Blanc	905	793	112	200,000	40,000
TOTAL INSTALLATION				1,551,900	174,500

UNDEVELOPED POWER SITES (Shown Hatched)

SITES	Elevations above sea level in feet: Headrace	Tailrace	Head in feet	Proposed ultimate installation H.P.
Rapide Sans Nom	633	523	110	252,000
Rapide des Coeurs	975	905	70	112,000
Rapide du Lievre	1061	978	83	124,000
Rapide Allard.	1150	1063	87	132,000
TOTAL POTENTIAL RESERVES				620,000



SKETCH P.S. 1.

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In 1926 the 540,000 h.p. hydro-electric development of the Saguenay Power Company, Limited, in which Shawinigan has a substantial interest, was constructed at Isle Maligne on the Saguenay River. To transmit the 100,000 h.p. purchased from this plant to the Quebec Terminal station of the Shawinigan system, a 136 mile 187,000 volt transmission line was constructed in 1927 through the rugged country of the Laurentide National Park.

The three main terminal stations, through which electricity from the various power houses is distributed, are located at Montreal, Trois Rivieres and Quebec City, while sub-stations are spread over the length and breadth of the system.

The coming of electricity to the Shawinigan territory brought in its wake an era of industrial development, which not only provided employment and wages to the people in the vicinity, but made necessary and profitable a complete chain of auxiliary occupations and enterprises—store-keepers, merchants, professional men, services and agricultural markets. Plentiful and low-cost electricity brought the aluminium industry into the St. Maurice Valley, paving the way for the Province to become a world leader in the production of this metal. Chemical industries also followed the development of electrical power. More than 70 per cent of Canada's textile industry is located in the Province of Quebec.

Forest wealth, including timber, has been and remains a reliable source of employment for the people of Quebec. The pulp and paper industry was among the first customers for Shawinigan power, and this union of forest resources with electrical power has brought to the St. Maurice Valley the greatest concentration of pulp and paper manufacturing plants in the world.

2. The Ontario Hydro-Electric Power Commission.

2·1. *History of the Commission.*—The Hydro-Electric Power Commission of Ontario is a corporate body administering a Province wide co-operative enterprise to produce and distribute electric power. The Commission was incorporated in 1906 by an enactment of the Ontario Legislature after consideration of recommendations made by advisory commissions appointed in response to public demand that the water power of Ontario should be conserved and developed for the benefit of all the people of the Province.

The Commission is a separate entity, a self-sustaining public concern endowed with broad powers to produce, buy and distribute electricity and to perform certain regulatory functions with respect to the activities of the electrical utility commissions of the member municipalities.

The state of electric power development in Ontario before the formation of the Commission is briefly as follows :—

The Niagara Falls Power Company undertook its first major electric power development at Niagara Falls, New York in 1893 and with the then existing knowledge in electric power generation and transmission they chose to generate power at 25 cycles. The Canadian Niagara Power Company came into operation in 1905 and was followed by the Ontario Power Company in 1906, both operating from the waters from the Niagara River at the neighbourhood of the Falls. The hydro-power generated by these two companies was at 25 cycles. At this time most of the power was exported to New York State on the opposite banks of the Niagara river. The Electrical Development Company came into operation in 1906 and transmitted a large part of its output to Toronto about 90 miles away.

At the outset of its operation in 1909, the Commission proceeded to construct transmission lines in order to supply the Niagara Power to the municipalities which first came into partnership. By the end of 1910, power was supplied to several municipalities. At that time power was purchased in bulk from privately owned companies.

As the years passed and its financial structure became strong, the Commission was able to embark upon the real business for which it had been set up. Due to the rapid growth of various industries, particularly during the Great War I, the Commission was pressed to keep pace with the demand and soon entered the field of generation. Several power plants had been designed and built at different parts of the Province all aimed to assist industrial expansion. At the same time, as opportunity occurred, privately owned power plants which could obviously be operated by the Commission more economically and with greater advantage, were purchased by negotiations.

Starting with the purchase of the plants of the Toronto Power Company and the Ontario Power Company on the Niagara River during the first World War, the Commission at the end of 1945 owned 54 generating stations with an installed capacity of about 1,720,000 h.p. and also purchased power to the tune of 953,000 h.p. for meeting the demand.

Then they operated the Queenston development with an installed capacity of 525,000 h.p. during the World War I and completed in 1925. In 1943, they completed the Decew Falls Development operated with the waters of the Welland Canal. This development, inclusive of the old plant, has a capacity of about 190,000 h.p.

The other important developments undertaken by the Commission are briefly as follows :—

Decew Falls (Niagara Region)—2 × 57,000 K.W.—1947— (Hydro).

Stewart Ville—63,000 K.W. 1948 (Hydro).

Aguasabon—40,000 K.W. 1948 (Hydro).

Hamilton Generating Station—63,000 K.W. (Steam) from January 1949—April 1950.

George Rainer Generating Station 42,000 K.W. June, 1950 (Hydro).

Pine-portage—93,000 K.W. 1950—1954 (Hydro).

Des Joachims—380,000 K.W. 1950 (Hydro).

Chenaux—120,000 K.W. 1950 (Hydro).

Otto-Holden (La Cave) Generating Station—204,000 K.W. 1952 (Hydro).

Niagara No. 2.—900,000 K.W. 1954 (Hydro).

J. Clerk Keith Station—264,000 K.W. (Steam).

Richard Hearn—400,000 K.W. (steam).

The Commission has now in its charge 65 hydro and 8 steam stations. Besides they are also purchasing power from Gatineau Power Company for about 340,000 h.p., from Beauharnois Power Company for 300,000 h.p. and from the Quebec Company for about 290,000 h.p.

In December 1951, the all system primary peak demand was 4,111,294 h.p. and by December 1955, this is expected to be around 5,771,600 h.p.

The major hydro stations in charge of the commission, may be broadly divided into—

(a) Niagara River Power Development.

(b) Ottawa River Development.

These are briefly dealt with later.

2·2. *Organization of the Commission.*—The organization of the Commission covers three main functions—Policy making, policy interpretation and action. The Commissioners constitute the final authority on policy decisions. The Government participation in the undertaking is limited to the degree of supervision of general policies necessary for the protection of the guarantees of the Province in connexion with the enterprise.

The General Manager and Chief Engineer is the principal executive officer and is responsible for carrying out the Commission's policy and decisions, principally through the means of the two main branches of the Organization—Engineering and Administration—each headed by an Assistant General Manager.

Three systems as indicated below are now in operation :—

(i) Southern Ontario System serving older and more populous parts of Ontario and the peninsula enclosed by the lakes of Heron, Erie, Ontario and St. Lawrence and the Ottawa rivers.

(ii) Thunderbay System serving the area at the lakehead on the north-western shore of the lake Superior.

(iii) Northern Ontario System which embraces both the north-eastern region and the north-western region excluding the Thunderbay System. Within the north-eastern region lie the geographical districts of Nippising, Sudbury, Manitoulin, Algoma and Chochrane. The north-western region includes the Patricia district.

Systems (i) and (ii) are referred to as the co-operative systems each of which serves a group of municipalites receiving power at cost under contracts established according to the provisions of the Power Commission Act. The Commission also serves directly certain industrial consumers and rural consumers within these systems. The Commission serves an area of 363,282 square miles.

2.3. *Financial and other features of the Co-operative Systems.*—The basic principle governing the financial operations of the undertaking is that electrical service is provided by the Commission to the municipalities and by the municipalities to the customers at cost. The cost includes not only all O & M charges, interest on capital, reserves for depreciation, contingencies, obsolescence and for stabilization of rates, but also a reserve for a sinking fund to retire the Commission's capital debt.

The undertaking from its inception has been entirely self-supporting with the exception that the Provincial Government through grants-in-aid, provides for 50 per cent of the capital cost of the rural distribution lines. This is done in pursuance of the Province's long-established policy of assisting agriculture. The Provincial Government also guarantees the payment of the principal and interest of all bonds issued by the Commission and held by the public.

With a few exceptions, all townships and 150 of the smaller villages are now served as an amalgamated rural division of hydro service with a uniform rate structure. No matter, where rural service is supplied in Ontario by hydro, all rural customers for the same class of service with the same consumption of electricity, pay the same amount.

The undertaking as a whole involves two distinct phases of operation. The first phase of operation is the provision of power either by generation or purchase and its transformation, transmission and delivery in bulk to individual municipal utilities, to large industrial consumers and to rural power districts. This is done by the Ontario Hydro-Electric Power Commission.

The second phase of operation is the retail distribution of electric power to consumers in the areas served by the various municipalities and throughout the rural areas of the Province. For the consolidated rural power districts, the Commission not only provides the power wholesale but also, on behalf of the respective townships, attend to all physical and financial operations connected with the retail distribution of energy to the consumers within the rural operating areas into which the consolidated rural power districts are divided for administrative purposes.

In cities, towns, many villages and certain thickly populated areas of townships, retail distribution of energy is in general conducted by the Municipal Commissions under the general supervision of the Hydro-Electric Power Commission of Ontario.

The total assets of the Commission on December 1951 amounted to $ 1,036,029,755 after deducting the accumulated depreciation of $116,945,857. Rural assets under administration at the end of the year amounted to $127,227,145 of which $ 63,015,165 has been provided by the Provincial Government in the form of grants-in-aid.

The Commission supplies power to 1,175 municipalities as indicated below :—

1. Municipalities owning their own distribution system and served through municipal electrical utilities—		
(a) Cost contract	316	
(b) Fixed rate contract	9	
		325
2. Municipalities served through other municipal electrical utilities.		5
3. Municipalities not in rural power districts and whose consumers are served directly by the Hydro-Electric Power Commission.		26
4. Municipalities in rural power districts where customers are directly served by the Commission on behalf of the municipalities.		819
		1,175

For most of the municipal electrical utilities revenues were sufficient to take care of costs of operation in spite of rising costs, and only 13 municipalities requested approval for an increase in retail rates.

The total number of Commission employees on December 1951 was 20,079.

2.4. *Power Generated and Purchased by the Commission.*—The power generated (Peak) and purchased in December 1951 by the Commission was as follows :—

	K.W.
(i) Southern Ontario System—	
Commission's Generating Stations	1,686,150
Power purchased	703,100
	2,389,250
(ii) Thunderbay System—	
Commission's generating stations	234,000
Power purchased	1,100
	235,100
(iii) Northern Ontario System—	
Commission's generating stations	317,400
Total power generated and purchased	2,941,750

The sources of power purchased for the Southern Ontario System as above is tabulated below :—

Sources of purchased power.	1951.
	K.W.
Canadian Niagara Power Company	15,000
Polymer Corporation	22,000
Gatineau Power Company	254,000
Ottawa Valley Power Company	85,000
Beauharnois Power Development	187,000
Maclaren Quebec Power Company	138,000
Miscellaneous	2,100
Total ..	703,100

The source of power purchased for the Thunderbay System is :—

Ontario Minesota Pulp and Paper Company	1,100

Total power generated in all systems	2,237,550
Total power purchased for the two systems	704,200
Total power generated and purchased by the Commission for all the three systems.	2,941,750

The utilization of the electrical energy sold by the Commission in the Province of Ontario is as follows :—

	PER CENT.
(*a*) Industries	67
(*b*) Domestic	21
(*c*) Commercial office and public buildings	7 to 8
(*d*) Rural service and street lights	4

The total number of consumers served by the Commission by the end of 1951 was 1,249,366 out of which 318,606 were rural consumers.

2.5. *Functional Divisions of the Commission.*—The various functional divisions of the Commission are briefly as follows :—

(i) *Supply Division.*—This comprises of Purchasing, Supply Control, Supply Inspection, Surplus Equipment and Materials and the Printing and Stationery departments. This division has about 650 employees or personnel divided up among the above five departments.

(ii) *Planning Division.*—This is responsible for—

(*a*) the maintenance of up-to-date information on potential sources of power ;

(*b*) the preparation of overall engineering plans, design of the component parts of the power systems including generation, transmission and distribution of power ;

(*c*) analysis of system performance characteristics and liaison with the Operations division regarding improvements and modifications to the existing systems ;

(*d*) liaison with the municipalities and direct contract consumers regarding new or increased system facilities ; and

(*e*) provision of technical advice and assistance to the Engineering and Operations division.

The Division comprises of four groups each dealing with one of the following :—

(1) Estimate and control.

(2) Record centre.

(3) System planning.

(4) Programme planning and control.

(iii) *Consumers Service Division.*—This comprises of six departments as follows :—

(*a*) The municipal service department ;

(*b*) Rural service department ;

(*c*) Industrial service department ;

(*d*) The rate study department to study the loads of the consumers, their requirements, the existing rates and to forward from time to time recommendations as to changes in rates necessary to provide adequate revenues and maximum benefit to the consumers;

(*e*) Statistical department to collect data to study load conditions, growth and growth trends and matters of similar nature ; and

(*f*) Electrical inspection department.

(iv) *Public Relations Division.*—This comprises of five departments as follows :—

(*a*) Frequency standardisation department.

(*b*) Graphic department to look after advertising, display, production, photography, etc.

(*c*) Administration department for the collection of information and preparation of surveys.

(*d*) Service department for liaison works, preparation of technical films and journals.

(*e*) Editorial department.

(v) *Comptroller's Division.*—This comprises of the following:—

(*a*) Treasury department.

(*b*) Accounting department.

(*c*) Internal audits department.

(*d*) Insurance department.

(*e*) Pension department for the personnel.

This division is responsible for the following :—

(*a*) Establishing policies and procedure on accounting and electrical matters and in the preparation of reports ;

(*b*) compilation of construction and capital costs, recording of revenues and expenditure and the annual allocation of the cost of the power ;

(*c*) preparation of the financial statements, reports and analysis ; and

(*d*) compilation of an annual budget in respect of revenues and operating expenses.

2.6. *Department of Frequency Standardization.*—About 2,339,000 h.p. of power in the southern part, of area of about 12,000 square miles, is of 25 cycle supply. Twenty-five cycle supply has now practically been superseded by 60 cycles in the the United States of America and in eastern and northern Ontario, so that the southern part of Ontario is now a

25 cycle island which makes inter-connexion with other systems difficult and costly. More over, 25 cycle equipment costs more than 60 cycle equipment and certain special equipments and appliances are required for 25 cycle supply. The use of modern lighting units is seriously retarded by the supply of electricity at this frequency as it results in an objectionable flicker.

These are some of the reasons that impelled the Commission to change-over all supplies gradually to 60 cycle resulting in the formation of this division which employs 846 personnel.

2.7. *Security branch.*—In each region there is a security officer to advise the manager and to study continually the needs of security.

2.8. *Personnel branch.*—This is to develop and recommend to the management of the Commission, policies and practices designed to maintain effective human relations throughout the organization and to interpret such personnel policies and practices as they are applied by the Commission.

2.9. *Research Division.*—The Ontario Hydro-Electric Commission maintain a research division as part of their engineering branch. The Commission felt even at the start that research and testing facilities would be essential to ensure efficient growth and to assist in providing continuous electric power economically. To meet this, a laboratory was set up in 1912, six years after the Commission was established. The laboratory has a staff of about 300 members occupying more than 70,000 square feet floor space. Facilities are available in the laboratory to provide for electrical, mechanical, structural, chemical and metallurgical investigation and testing for all phases of the Commission's operations. The laboratory is one of the largest and best equipped in Canada and is recognised both nationally and internationally as a pioneer and authority in several fields relating to generation and distribution of electrical energy.

The research division is primarily a service organization maintained to provide specialised advice and highly technical assistance for all other divisions within the Commission. It is responsible for the development, standardization and control of all testing procedure, technical information relative to specifications and for the Commission's scientific and engineering research.

The main problems dealt with by the research division are as follows :—

(1) Transmission and distribution problems including those of making satisfactory joints and connexions particularly when aluminium conductors are involved.

(2) Grounding problems.

(3) Linascope-radar type instrument for locating faults on telephone and power lines.

(4) Bolometer for measuring infra-red radiation to survey transmission line joints, to determine if any are operating at abnormal temperatures.

(5) Soniscope, an ultrasonic device to indicate the depth of cracks in concrete structures and also the conditions of the concrete *in situ.*

(6) Investigation of telephone, radio and television interference problems.

(7) Single pole reclosing of high voltage systems and field forcing on large synchronous condensers.

(8) Problems of accuracy in all billing meters.

(9) 'Hipot' bushing tests for testing of insulators and bushings.

(10) Vibration of conductors.

(11) Transformer oil.

3. The Tennessee Valley Authority.

3.1. *History.*—The T.V.A. (Tennessee Valley Authority) is the tale of a wandering and inconstant river that has now become a chain of broad and lovely lakes which people enjoy, and on which they depend in all seasons for the movement of barges of commerce. It is the story of how waters once wasted and destructive have been controlled and now work night and day creating electrical energy to lighten the burden and drudgery of people. It is a tale of fields grown old and barren with years, but which now are vigorous with new fertility, lying green to the sun, of forests that were hacked and despoiled, now protected and refreshed with strong and young trees.

When T.V.A. was created by an Act of Congress on May 18, 1933, it was specifically authorized to construct water control projects to maintain a 9-foot navigation channel from the mouth of the Tennessee River to Knoxville to provide for the control of floods, to generate electricity from the power made available by the water control structures and to provide other related benefits. By 1952, T.V.A. in carrying out this programme had completed 18 dams (7 on the main river and 11 on the tributaries).

In addition to the dams constructed by the T.V.A. the Tennessee River System includes 9 dams (5 major and 4 minor) which T.V.A. acquired and ten dams owned by the Aluminium Company of America and which are integrated into the system.

The present T.V.A. system comprises of 37 dams and will in the near future be increased to 42 dams with the completion of the 5 dams under construction. The mean annual rainfall over the drainage area is about 51 inches but varies from year to year from 37 to 63 inches.

Heavy cyclonic storms moving across the Tennessee Valley between December and April become potential causes of widespread major floods in the valley. Between June and October the area is subject to both cyclonic and local storms and intense rains accompanying the passage of decadent hurricanes. These summer storms may cause devastating floods in the mountainous portion of the valley. Protection against damage by such floods was one of the principal reasons for building the dams, and in the design and operation of the dams and reservoirs, flood control is one of the primary purposes.

The natural river flow at the site of Kentucky dam before any of the dams were built ranged from a minimum of 4,500 cusecs in 1925 to a maximum of 500,000 cusecs in 1897 and an average of 65,000 cusecs from 1889 to 1943. At Fort Loudoun dam it varied from 11,600 cusecs in 1925 to 300,000 cusecs in 1867 with an average of 13,800 cusecs for 1899 to 1943.

In the multi-purpose pattern of the T.V.A. Programme, the dam and reservoirs were built and are operated for flood control, navigation and power generation and these three uses are given preference in the sequence in which they are listed.

The amount of storage is normally held below a carefully worked out guide curve for each reservoir, based upon a study of storm occurrence over the entire period of record. If a local storm fills one or more reservoirs above their guide curves, they are drawn down, by spilling if necessary immediately after the flood danger is over.

If a storm occurs in the Ohio Valley or in the Mississippi Valley, the Tennessee River discharges are reduced at the right time to avoid adding to the flood crest.

The Tennessee Valley Region, two decades ago, was primarily an agricultural region with relatively few opportunities for industrial development. Farms were small and farm families large so that agricultural workers were usually under-employed. Many people migrated from this region to the industrial centres in the north.

The area through which the Tennessee River flows is now an entirely different region from what it was ten years ago.

In ten years, the dams T.V.A. has built have made the region the largest producer of power in the United States of America. Since then, the T.V.A. has taken some long strides towards a better balance between industry and agriculture, towards higher incomes for its people. This region was able to contribute greatly to the prosecution of the World War II and is today an important material defence arsenal containing atomic energy, aluminium and heavy chemical plants, as well as many other defence and associated industries. Engineering a river, with large-scale modern machinery and rebuilding soil, that for generations has been losing its vitality, are tasks of a different tempo. The gullies are being healed, the scars of erosion are on the mend slowly but steadily. The cover of dark green, the pasture of deep meadow and upstanding fields of oats and rye, the marks of fertility and productiveness are on, everywhere. Matting, sloping, seeding and sodding have given protection to eroded banks on the scores of thousands of acres. A 150 million seedlings trees have been planted on hundreds of thousands of acres of land from T.V.A. nursery stock alone. When the T.V.A. began its work in 1933, of the total of $8\frac{1}{2}$ million acres of cultivated land in the valley, erosion in varying degrees had damaged 7 million acres. On more than a million acres, the top soil had entirely disappeared.

A large part of the land was in a badly rundown state of cultivation. Some of the fields had even been abandoned and had a thick cover of broom sedge, pine, persimmon and bushes. No lime phosphate or fertilizer was ever used. With the ability of the people, to take advantage of modern agricultural knowledge, electric power and machinery, these have now been converted to rich pastures and fields. A farm that could originally produce barely 10 bushels of corn, is now producing 50 to 60 bushels of oats per acre.

The system of reservoirs on the Tennessee River and its tributaries operated by the T.V.A. since 1936, for the multi-purposes of navigation, flood control and power is something of a pioneer in this field. This is primarily for the purpose of promoting navigation and controlling floods and so far as may be consistent with these purposes for the generation of power.

The most important factor in the successful operation of a multi-purpose water control system is that the system shall have been planned and designed for the method of operation to be carried out.

There are three different methods of approach as to the design of multi-purpose projects involving flood control.

(1) The reservoir must at all times be kept empty for flood control.

(2) There must be a designated volume or definite layer in the portion of the reservoir reserved for flood control and that other uses cannot be permitted to encroach in this volume at any time.

(3) That this space in a reservoir may be used both for flood control and other purposes at different seasons of the year.

In planning the reservoirs forming the Tennessee River System, the T.V.A. have adopted the method of multi-purpose operation which most economically produces reliable flood control, adequate navigation facilities and substantial power production.

The operation of the system has been carried out for the past several years as planned. During that time, a number of moderately large floods have occurred but have been successfully controlled. No extremely large floods have however been experienced but the planned reservation of the reservoir space for flood control have been maintained and the occurrence of such a flood, may be awaited with confidence as it will be controlled as planned.

Of the total development, 65 *per cent is allocated to power,* 15 *per cent for navigation and* 20 *per cent for flood control.*

3.2. *The T.V.A. Power System.*—The power system owned by the T.V.A. includes 32 major dams and power houses, 3 modern steam plants, 4 older steam plants and several minor hydro and steam plants. The total installed capacity is about 4·5 million KW. inclusive of the 5 major dams and generating stations of the Aluminium Company of America on the tributaries of the Tennessee River. Three dams and generating stations of the United States Army Engineers on the Cumberland River are included in the integrated system operated by the T.V.A. The generating stations are all inter-connected by means of 8,500 miles of high voltage transmission lines.

The area served by the T.V.A. covers practically all the Tennessee, North Alabama, North-eastern Mississippi, South-western Kentucky, and small parts of Georgia, North Carolina and Virginia covering about 80,000 square miles and a population of about 5,000,000.

The T.V.A. is now building 7 large steam plants, viz.—

675,000 KW. plant at Johnson Ville (completed),

675,000 KW. plant at Widows Creek,

1,260,000 KW. plant at Kingston,

1,350,000 KW. plant at Shawnee,

720,000 KW. plant at Colbert,

450,000 KW. plant at Gallatin and

360,000 KW. plant at Johnsevir.

At the end of 1952, some 4·5 million KW. of steam and 0·5 million of KW. of hydro power projects were under construction. Completion of these projects will bring the capacity of the T.V.A. system to 9·5 million KW. by 1956.

The T.V.A. used about 2 million tons of coal in 1952 and in a few years, this is expected to increase to 18 million or more tons.

The integrated power system, including the hydro plants of the United States Army Engineers' on the Cumberland River and the Aluminium Company of America's hydro plants on the Little Tennessee river, generated 19·7 billion KWH. during 1952. An additional 3·8 billion KWH. of power was obtained for other systems by purchase or interchange.

Of the 19·7 billion of KWH. the T.V.A. contributed 12·2 billions (hydro), the United States of America Army Engineers' Cumberland plants 1·4 billion and Alcoa 1·8 billions. About 4·3 billions of units were supplied by the T.V.A. steam stations, which used about 1·06 lb. of coal per KWH. on an average. The average cost of coal was $ 4·93 per ton.

The power business in the T.V.A. is conducted under a close working relationship between the T.V.A. which produces electric power and local electric systems which distribute that power to the ultimate consumers. There are now about 50 co-operatives and 96 municipalities comprising the distributor group and they now serve about $1\frac{1}{4}$ million consumers. The decentralization of the power distribution function among these local agencies, places control in the hands of those who use electricity. Under this set-up power distribution is carried out under local boards intimately familiar with and responsible to their communities. Among the 900 or so members of these boards, 266 are farmers, 136 merchants and 57 bankers.

In 1952, the financial results of the scheme were as follows :—

Capital outlay—555 million Dollars.

Net income—26 million Dollars.

Return—4·7 per cent.

Over the 19 years of T.V.A.'s existence, the earning averaged 4·25 per cent. The Government borrowed money at 2 per cent during this period.

3.3. *Organization.*—The organizational set up of the T.V.A. is shown in Chart 1.

The Power Department consists of four divisions, viz.—

1. Division of power supply.
2. Division of power operation.
3. Division of power utilization.
4. Division of power engineering and construction.

3.3.1. *Division of power operations, its organization and functions.*—The division of power operations is responsible for the operation and maintenance of the T.V.A. Power System and for related activities of the office of the Director of Power Operations, the Power Production Branch, the Electrical Laboratory and Test Branch, the Power System Operations Branch, the Power System Service Shops Branch, and the Transmission System Maintenance Staff. The various branches of the division are shown in Chart 2.

Maintenance organization of each district is shown in Chart 3.

TENNESSEE VALLEY AUTHORITY.

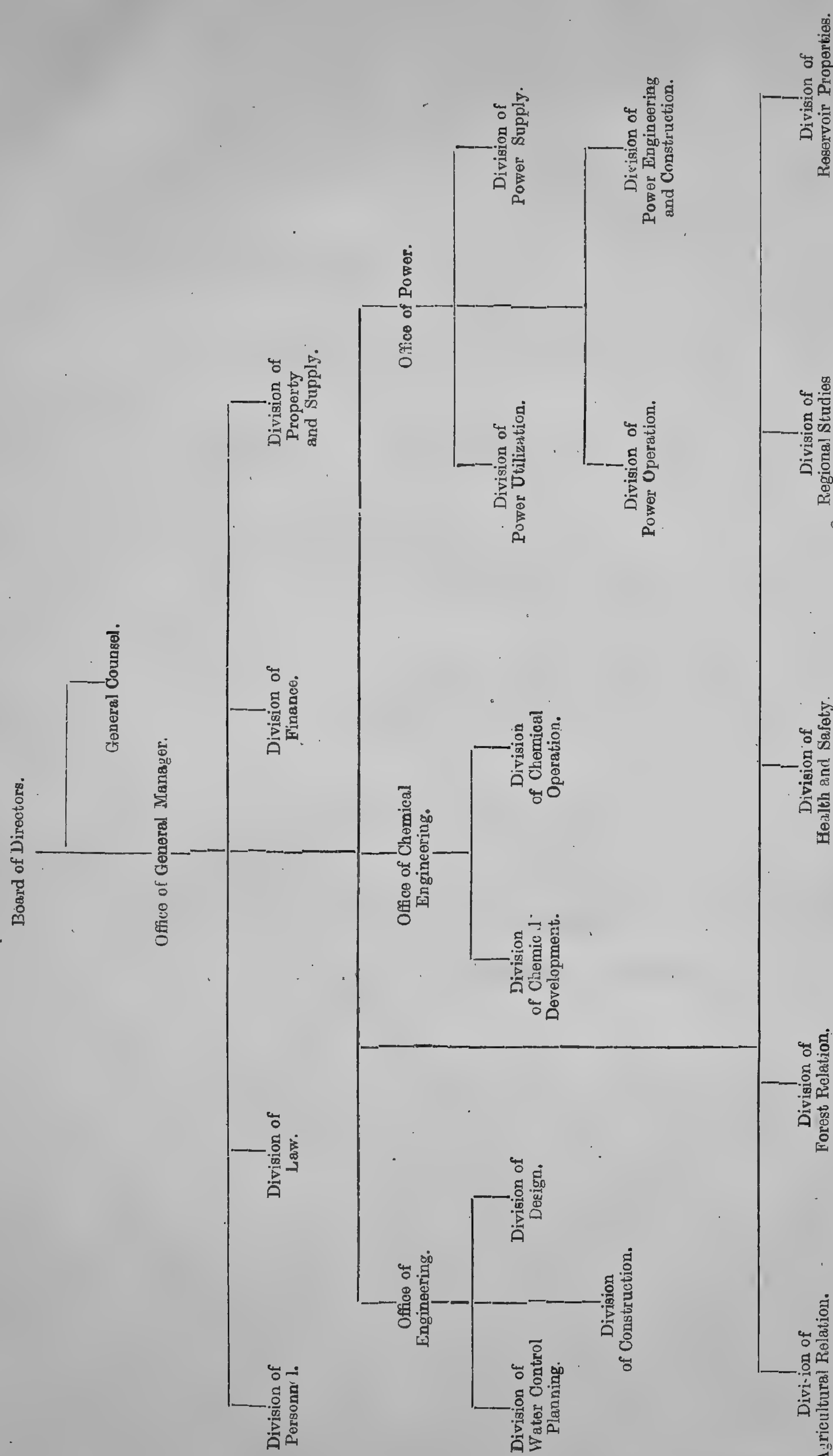


CHART 1.

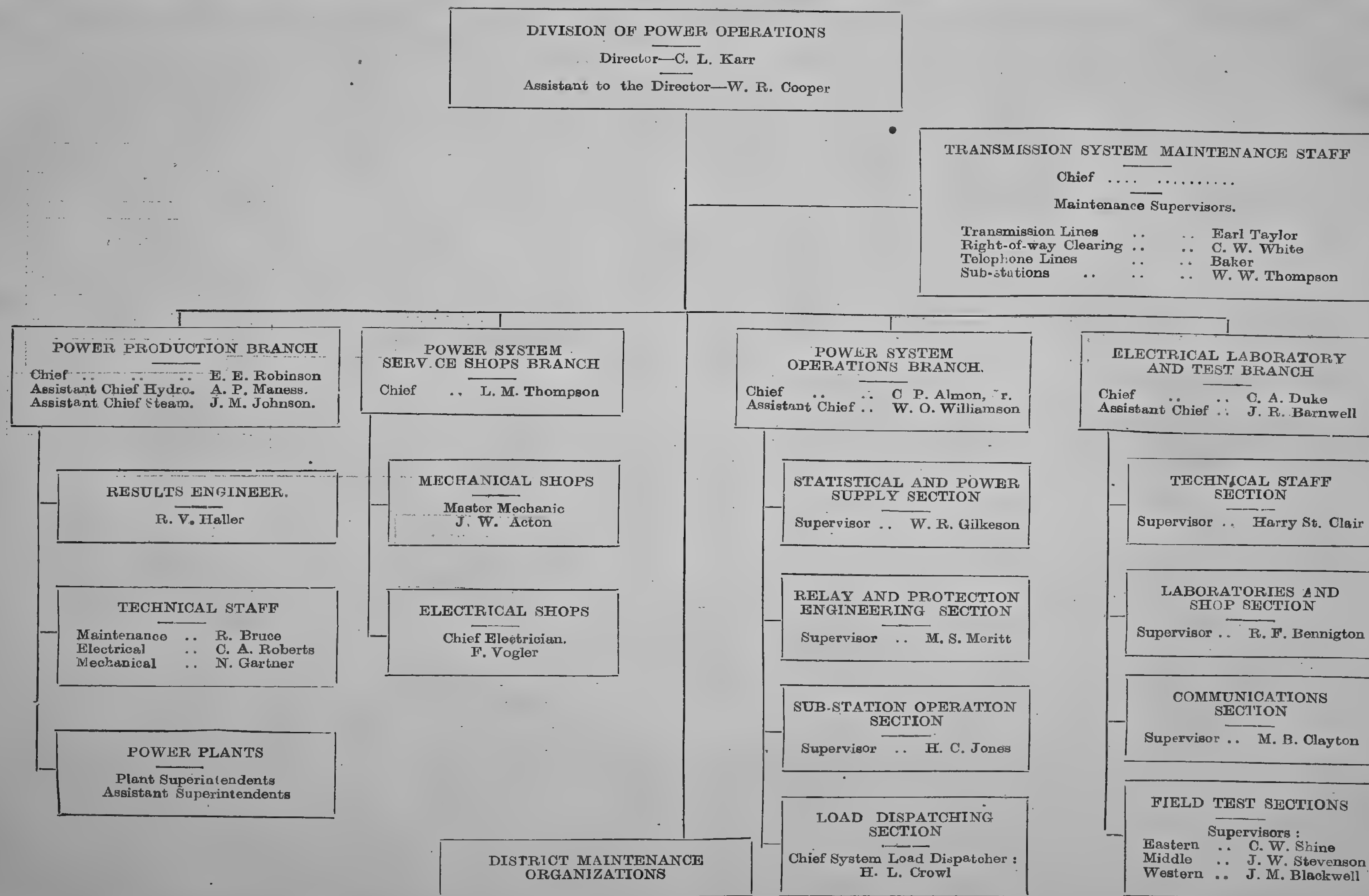

DIVISION OF POWER OPERATIONS
Director—C. L. Karr
Assistant to the Director—W. R. Cooper
TRANSMISSION SYSTEM MAINTENANCE STAFF
Chief ....
Maintenance Supervisors.
Transmission Lines .. .. Earl Taylor
Right-of-way Clearing .. .. C. W. White
Telephone Lines .. .. Baker
Sub-stations .. .. .. W. W. Thompson
POWER PRODUCTION BRANCH
Chief .. .. .. E. E. Robinson
Assistant Chief Hydro. A. P. Maness.
Assistant Chief Steam. J. M. Johnson.
RESULTS ENGINEER.
R. V. Haller
TECHNICAL STAFF
Maintenance .. R. Bruce
Electrical .. C. A. Roberts
Mechanical .. N. Gartner
POWER PLANTS
Plant Superintendents
Assistant Superintendents
POWER SYSTEM SERV.CE SHOPS BRANCH
Chief .. L. M. Thompson
MECHANICAL SHOPS
Master Mechanic
J. W. Acton
ELECTRICAL SHOPS
Chief Electrician.
F. Vogler
DISTRICT MAINTENANCE ORGANIZATIONS
POWER SYSTEM OPERATIONS BRANCH.
Chief .. .. C. P. Almon, Jr.
Assistant Chief .. W. O. Williamson
STATISTICAL AND POWER SUPPLY SECTION
Supervisor .. W. R. Gilkeson
RELAY AND PROTECTION ENGINEERING SECTION
Supervisor .. M. S. Meritt
SUB-STATION OPERATION SECTION
Supervisor .. H. C. Jones
LOAD DISPATCHING SECTION
Chief System Load Dispatcher :
H. L. Crowl
ELECTRICAL LABORATORY AND TEST BRANCH
Chief .. .. C. A. Duke
Assistant Chief .. J. R. Barnwell
TECHNICAL STAFF SECTION
Supervisor .. Harry St. Clair
LABORATORIES AND SHOP SECTION
Supervisor .. R. F. Bennigton
COMMUNICATIONS SECTION
Supervisor .. M. B. Clayton
FIELD TEST SECTIONS
Supervisors :
Eastern .. C. W. Shine
Middle .. J. W. Stevenson
Western .. J. M. Blackwell

CHART 2.

Typical District Maintenance Organization.

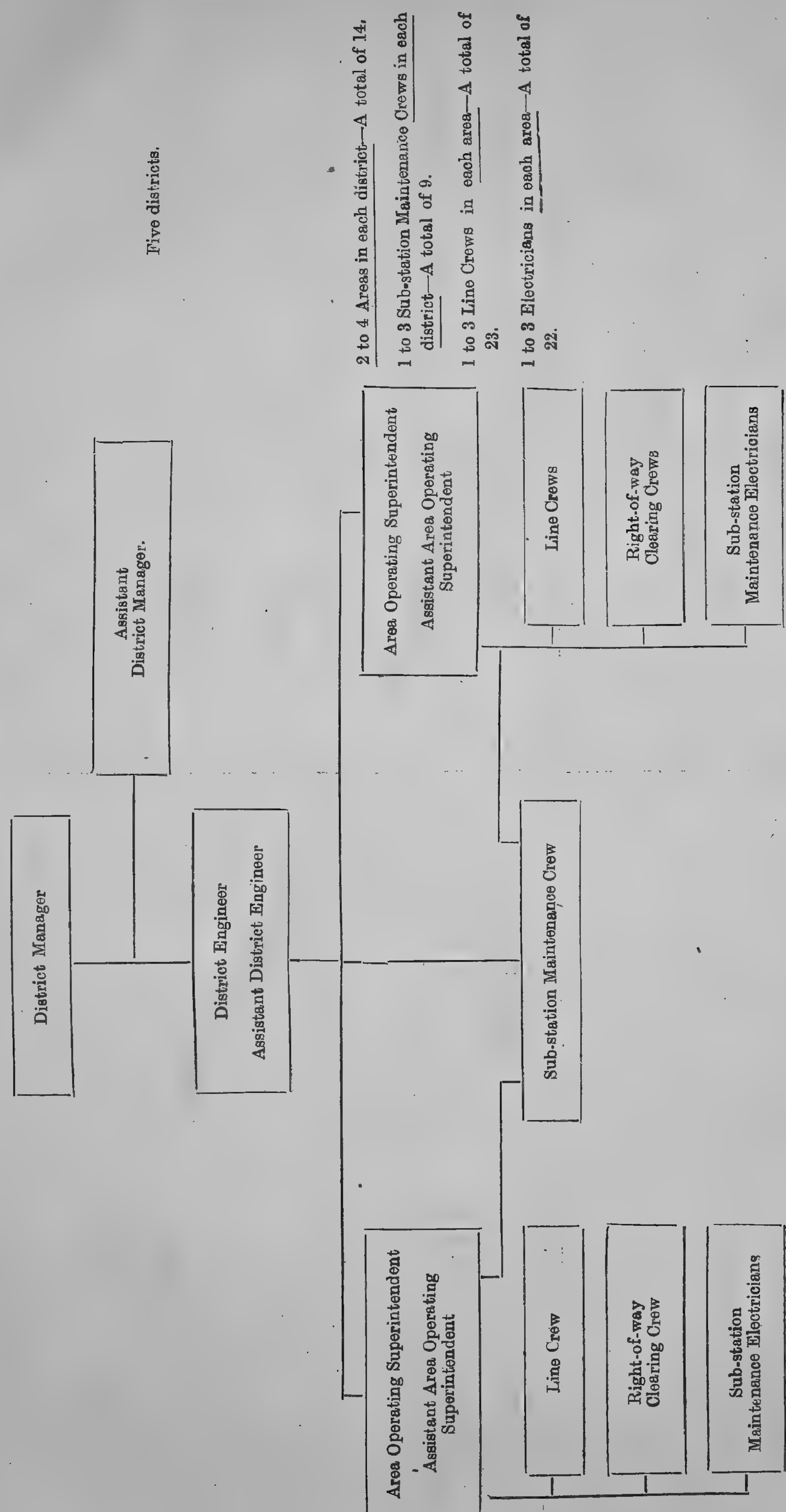


CHART 3.

3.3.2. *Power Production Branch.*—The Power Production Branch is responsible for the operation and maintenance of all hydro-electric and steam electric generating plants, including the water control facilities at the various dams.

These activities are directed by the Chief of the Branch, with two principal assistants, who are responsible for the hydro and steam plants respectively. The central office of this branch also includes an engineering staff, which makes studies and recommendations concerning operating practices, plant maintenance, rehabilitation of old plants, plant improvements, and miscellaneous engineering matters. An important function of the central office staff is to review and make recommendations on plans and designs submitted by the office of the Chief Engineer for new plants and for extensions and modifications of old plants.

The Chief of the branch co-ordinates operating activities among the plant operating organizations, construction organizations, and equipment manufacturers during the intitial operation of new plants or new equipment in old plants and is responsible for the final acceptance of the units for commercial operation.

The assistant chief of the branch in charge of the hydro plants is responsible for keeping constantly in touch with the Power Plant Superintendent at each hydro plant and for being generally familiar with the operating and maintenance conditions at these plants. He co-ordinates maintenance schedules between plants and generally supervises the activities of the power plant superintendents, giving them advice and assistance on administrative, operating and maintenance problems. He is responsible for the execution of the hydro plant operator training programme and arranges for transfers and promotions of operating and maintenance personnel. When new generating units are installed, this employee co-ordinates the testing and initial operations for the Division of Power Operations. There are 24 hydro plants involved.

This employee also reviews the general designs and plants for all new hydro projects and additions, recommending such changes as are desirable from an operating standpoint. In this way the design engineers are constantly obtaining the benefit of operating experience, enabling them to make improvements in the design of each new project.

The assistant chief of the branch in charge of the steam plants has similar responsibilities in connexion with the operation and maintenance of all steam plants. He is assisted in this work by the Results Engineer, who is responsible for continually reviewing the performance of all plants, seeing that the boilers and turbines continue to operate at the best possible efficiency; recommending changes in operating practice, installation of control equipment, repairs or other maintenance work on boilers, turbines, condensers, and other auxiliary equipment; and keeping in touch with fuel analyses, boiler feed water treatment, and all other conditions affecting the efficient operation of the steam plants. In general, it is the responsibility of the Results Engineer to see that the cost per kilowatt hour at each steam plant is kept at a minimum.

The operation and maintenance activities at the plants are carried on under the supervision of seventeen power plant superintendents, each of whom is responsible for one plant or a group of plants. At each of the locations where both hydro and steam plants are operated, as at Hales Bar, Watts Bar, Wilson and Ocoee No. 1, there is one Superintendent in charge of both plants; similarly groups of hydro plants, such as Norris, Douglas, and Cherokee, are supervised by one Superintendent, with an assistant at each plant.

The Power Plant Superintendent supervises all operation and maintenance activities at his plant. He is responsible for seeing that the necessary plant organization is maintained and that a sufficient number of operating and maintenance employees are available at all times for all routine and emergency work that may be required.

At the T.V.A. constructed hydro plants, there are only three or four operating employees on each shift. These include a Senior Operator, a Turbine Operator, a Switchboard Operator and in the case of the larger plants, an Assistant Turbine Operator. This small number of employees results from improvements in design, which have reduced operating costs to an absolute minimum. In contrast, the Wilson Hydro plant, which was completed about 25 years ago, requires ten operating employees on each shift. This large number is, however, due in part to the large number of installed units and extensive areas involved.

The T.V.A. has in general two types of hydro plants ; the main river plants most of which operate at low heads and are operated continuously to utilize all available stream flow, and the tributary plants which are high head plants and are operated to meet stream flow conditions and system transmission requirements.

Of the main river plants all except two have been built by the Authority. Of these two the Hales Bar Hydro Plant, constructed about 35 years ago, is the older. When this plant was built, low head turbines of large sizes were not available, and it was necessary to mount three water wheels on a single shaft to obtain an output of 3,500 KW. at the rated head of 36 feet. Because of this capacity limitation it was necessary to install 14 units to obtain a capacity of about 50,000 KW.

The Wilson Plant is the largest hydro plant on the system, with a capacity of 352,200 kilowatts. There are 14 units at this plant, including 6 which have been installed by the Authority.

All the T.V.A. built plants on the main river have turbines of the propeller type. Except at Wheeler, these turbines are equipped with Kaplan control, which provides for automatic adjustment of the blade angle in order to operate at the highest efficiency at available the head. The turbines at Wheeler are of the fixed blade propeller type.

3.3.3. *Power System Service Shops Branch.*—The Power System Service Shops Branch provides both shop and field service as required for major repairs to generating plant and substation equipment. This branch also provides repair service for other divisions of the Authority and, to some extent, for outside agencies, such as other Government organizations and T.V.A. Power contractors.

This organization is under the supervision of the Chief, Power System Service Shops Branch. He is assisted by a Chief Electrician and a Master Mechanic, who are in charge of the electrical and mechanical activities respectively.

There is a large machine shop which handles all mechanical repair work and is often called upon in emergencies to fabricate replacement parts such as gears, shafts, bearings and other items.

The electrical repair shop is equipped for making major repairs to large power transformers, oil circuit breakers, motors, and all other types of electrical equipment. In many cases, it has been necessary to rewind or rebuild such items as transformers and circuit-breakers completely, in this shop.

The coil winding and motor repair shop is equipped for repairing motors of almost any size or voltage and for making up new coils for replacement in transformers and other types of equipment.

The welding shop performs all kinds of acetylene and electric arc welding and metal spraying for repairing broken castings, fabricating steel parts, building up worn shafts, and applying corrosion resisting surfaces to other metals.

A great deal of welding is done in the field to build up worn places on water wheels following cavitation. New wheels are always subject to cavitation at certain points on the surface although it is impossible to determine in advance just where this wear will take place. Therefore, after the wheels have been in service for several months, the pitted areas are filled by welding with a wear-resistant metal, after which further welding is not usually required under ordinary conditions for a period of many years.

In the blacksmith shop repair parts are made by forging and tools such as chisels, drills, and bars are made or repaired. This shop is also equipped for shearing, punching and rolling sheet metal.

A painting crew is maintained for painting the plant structures and equipment. The men in this crew are trained especially for this work, which involves special hazards due to the presence of energised or rotating equipment. A considerable amount of painting is also done in the shop on equipment which has been fabricated or sent to the shop for repairs.

A labour crew is also maintained for the purpose of cleaning transformer coils and tanks and generator windings, for cleaning structures and equipment in preparation for painting, and for handling material and performing all sorts of work not requiring skilled labour.

3.3.4. *Power System Operations Branch.*—The Power System Operations Branch is responsible for co-ordinating the operation of the power system and water control facilities for the operation of all attended substations, for conducting technical studies and investigations required for the operation of the system and for reviewing and making recommendations on power contracts and on proposed system additions and changes.

This work is carried on under the supervision of the Chief of the Branch. The branch is composed of a central office staff and four sections, viz., the Statistical and Power Supply, Substation, Relay and Protection, and Load Dispatching Sections.

In addition to the general supervision and administration of the activities of the branch the central office staff schedules the amounts of power to be purchased from or sold to interconnecting utility companies, negotiates preliminary terms and conditions of purchase or sale of power on short-term agreements, reviews power contracts, prepares transmission line loss calculations and co-ordinates the activities of the branch with other branches and divisions of the Authority.

This staff also makes recommendations regarding proposed changes to the Authority's power and communication systems. Close co-operation is maintained between this branch and the Power Engineering and Design Branch of the Division of Power Engineering and Construction. All proposed electrical modification and additions are reviewed in detail before and during the preparations of design specifications. All specification drawings are reviewed and certified prior to their release to the Power Construction Branch. The actual physical construction is co-ordinated between the area districts, the Division of Power Engineering and Construction, and the Division of Power Operations to offer the least hazard to customer service and to expedite construction work.

The Statistical and Power Supply section prepares load schedules to obtain the maximum usefulness of hydro generating facilities and resources consistent with the use of the water for navigation, flood control and other purposes as required by the Tennessee Valley Authority Act and to utilize the steam generating equipment and transmission ties with other power systems to the greatest economic advantage. Very close co-operation is maintained with the Division of Water Control Planning, in co-ordinating the use of the water and essential limitations are thus established within which this branch operates.

This section, working in close co-operation with the Division of Power Utilization, makes studies of future power requirements and supply under various possible conditions in order to determine the most effective means of utilizing the available water and other power resources. Special investigations are made from time to time on the basis of operating and maintenance requirements of the system for recommending needed modifications or additions to power facilities. Billing data covering transactions with all large power customers and interconnecting electric utility companies are prepared monthly and transmitted to the Division of Finance.

Statistical data concerning generation, interchange, and distribution of energy, loading and performance of equipment, operating expenditures, operating personnel, and interruptions to service of wholesale contractors, sub-stations and transmission lines are compiled and reported periodically and by special request for use by this and other divisions of the Authority, as well as by other Federal agencies and the Edison Electric Institute.

The Sub-station Section is responsible for the operation of all attended sub-stations, including both personnel and equipment. This section works in close co-operation with the Load Dispatching, Statistical and Power Supply, and Relay and Protection Sections, as well as with the Chief Transmission System Maintenance staff, regarding loading and voltage conditions and the operating performance of the sub-station equipment.

The Sub-station Supervisor, who is the head of this section, is responsible for the assignment and scheduling of operators and for the administration of the student operator training programme in so far as sub-station operation is concerned. He is also responsible for reviewing sub-station charts, log sheets, and other records, compiling essential data concerning equipment operation and recommending necessary changes in cases where equipment become inadequate or overloaded or where voltage or other service conditions are unsatisfactory.

The work of this section also includes engineering studies and calculations required to determine the ultimate capacity of transformers and other equipment and to predict necessary equipment changes as far in advance as possible.

The Relay and Protection Section is responsible for operating and application engineering in connexion with the primary transmission system and the various sub-stations, including those at the generating plants on matters pertaining to system operations.

The Authority's Power System is one of the most complex in existence from the standpoint of the number of plants and lines, the number of inter-connexions with other utilities, the magnitude of the power flow on major inter-connecting lines between plants, and the fluctuation of power flows with the constantly changing water and load conditions from one end of the system to the other. For this reason they have relaying problems requiring constant study by a group of specially trained engineers who must keep continually informed of the system characteristics and load requirements.

The engineering investigations of the proposed system additions or changes consist of checking the operating limits of equipment under normal and abnormal conditions, flexibility of switching connexions, characteristics and ratings of switch-gear, tap adjusting ranges, and transformation ratios. Studies are made of the types of relaying necessary to discriminate between load and fault conditions and to remove from service the minimum amount of equipment in the event of a fault. The operating ranges of the protective equipment required for normal and abnormal load conditions are determined, and appropriate connexions are specified. In connexion with the operation of the protective equipment, thought is given to the need for automatic equipment required for the immediate restoration of service or normal connexions following abnormal conditions. These studies must necessarily be supported by technical reports based on operating data on similar equipment or installations.

When the principal features of the protective equipment have been determined and approved for installation, a final analysis is made of the effect of the changes on the entire system and detailed computations are prepared for all the affected parts. These computations include the loading of transmission and transformation facilities at other points ; reactive power distribution from condensers and generators ; changes in voltages at other locations ; and effect of the new installation on fault currents, voltages, and phase angles at other locations. The resulting data are then used to determine the possible electrical stresses on insulation resulting from unsymmetrical faults, interrupting duty of oil circuit-breakers, and the likelihood of system instability.

As detailed drawings are prepared and relays and similar devices purchased, wiring diagrams are checked and detailed adjustment data are issued to the Electrical Laboratory and Test Branch for the field adjustment of the equipment. This information must be prepared and made available well in advance of the placing of the equipment in commercial operation.

The Authority's protective equipment is co-ordinated with similar equipment owned by inter-connected utilities and customers. This involves extensive study of the customers' systems.

Instructions are prepared and made available to the Load Dispatching Section for use in compiling operating procedures. Similar information is also made available to maintenance personnel for use in explaining the operating characteristics of the equipment and the results to be expected from the various tests.

The test reports submitted by the Electrical Laboratory and Test Branch are analysed carefully to determine whether adjustments have been made in accordance with the original adjustment data furnished and also to verify the correctness of equipment data supplied by the manufacturer.

An important function of this section is the computation of voltage changes under varying load conditions with regard to both magnitude and phase angle. Studies are made of power and reactive distribution in parallel or net-work circuits. From these computations and field information obtained by the use of recording instruments, instructions are issued for the adjustment of voltage regulators on generators and synchronous condensers and contact-making voltmeters on feeder type voltage regulators.

Another phase of system operation includes the control of loads transferred between the inter-connected systems. Load control is extremely important in orders that reserve capacity requirements can be held to a minimum and the capabilities of each inter-connected system and transmission line used to the best advantage. The Authority's system inter-connects with the transmission and generation facilities of eight utility concerns, one Government hydro-electric development, and one large manufacturing company through large capacity transmission lines. The control of loading on these lines is accomplished by means of telemetering devices operating over carrier current channels and automatic load control equipment installed at the generating stations. The satisfactory operation of this equiqment requires the preparation of detailed instructions for the adjustment of prime mover governors, various load control devices, and associated telemetering equipment. This work includes the analysis of tie line and generating station load charts that are received daily and the interpretation of these charts for the purpose of determining what changes and adjustments are necessary.

The Load Dispatching Section co-ordinates the operation of the various generating plants, both as to electrical connexions and as to loading. All changes are directed by the power system dispatchers in order to ensure the efficient operation of the system as a whole within the limitations of contractual obligations and their own operating requirements. Loading schedules as prepared by the Statistical and Power Supply Section are followed as closely as system conditions permit.

The power system dispatchers direct all switching operations on the Authority's primary electrical system. This centralized control is required to assure the proper handling of all operations and to obtain maximum safety to employees engaged in maintenance or construction work. Detailed reports are maintained on each switching operation, and the system connexions are indicated on the power system dispatchers' diagram board in order to keep an up to the minute record of system connexions.

The power system dispatchers direct all changes in settings on frequency and tie line load regulating equipment in order to obtain a maximum of co-ordination in the control of loading on the Authority's system and on inter-connexions with other electric utilities' systems. The control of loading on the tie lines requires close observation, and it is the power system dispatchers' responsibility to order changes of automatic controls and switching operations to meet the varying conditions on the electrical system. Records are kept on all changes in connexion with these operations, and a summary report is prepared covering inter-connexion operations. This information is co-ordinated with other organizations within the Authority to assist in the maintenance and improvement of facilities.

During emergency conditions the power system dispatchers direct all switching operations necessary to restore service and to isolate equipment which is in fault. These operations to restore service are generally made in accordance with procedures prepared for this purpose, while the switching operations performed to isolate defective equipment are varied with the conditions surrounding the individual case. These procedures are so written that they can be followed by the sub-station operators to restore service even if communication is not available.

All clearances on electrical equipment are handled by the power system dispatchers in order to hold service interruptions to an absolute minimum commensurate with the safety of the persons who hold clearances and those who operate the switching equipment. Definite procedures for handling clearances are prepared and submitted by the Load Dispatching Section. Detailed records are made on each clearance transaction, and the equipment which is de-energised for maintenance or construction work is indicated on the dispatchers' diagram board.

Water control operations are co-ordinated between the various dams in accordance with instructions issued from time to time by the Division of Water Control Planning and co-ordinated by the Statistical and Power Supply Section. In order that proper control may be exercised on this regulation, the power system dispatchers keep accurate hourly information on stream flow, reservoir elevations, and water releases at each point.

The proper regulation of system voltage requires very close attention by the power system dispatchers because of the constant changes in loading and electrical connexions. Every effort is exerted to maintain the load conditions over the entire system within very close limits. In order to keep informed of changing conditions, voltage readings are received and recorded at regular intervals from all principal sub-stations and generating plants.

Reports covering all interruptions of service to customers, hourly generation at all power plants, energy obtained from inter-connexions, rainfall, reservoir elevations, stream flow, system voltage, switching operations, clearances, and general system conditions are prepared daily for use in the efficient operation of the power system and are distributed to all interested offices for their use. Examples are the Daily System Interruption Report sent to the area districts; the Daily Hydro Generation Report sent to the Division of Water Control Planning; and the Daily System Operating Report sent to the various Divisions of Power.

An accurate clearance and switching list of personnel is maintained from information submitted by the area districts and other divisions for the guidance of the power system dispatchers in issuing clearances on electrical equipment and performing switching operations.

The power system dispatchers are required to notify responsible district or plant personnel as soon as possible when failures occur on equipment in their area and also to keep other interested branches within the Division of Power Operations informed so as to expedite repairs and the restoration of normal conditions. A system-wide telephone directory

containing the names of all persons competent to perform switching operations is prepared by the Load Dispatching Section and issued to all interested persons. Operating procedures are prepared for each sub-station and generating plant to be used in the routine and emergency operation of electrical equipment. These procedures are distributed to the various stations and to the district organizations.

3.3.5. *Electrical Laboratory and Test Branch.*—The Electrical Laboratory and Test Branch is responsible for electrical and chemical testing, for the maintenance of meters, relays, instruments, load control and telemetering equipment, and other similar equipment on the entire power system and for furnishing adequate testing instruments and facilities. It is also responsible for the maintenance of carrier current and other electronic equipment for co-ordinating the operation and the maintenance or supervision of the maintenance of all TVA-owned communication facilities used for power system operation and for reviewing and making recommendations on plans and designs pertaining to metering, relaying, various types of control instruments and schemes, and all communication or signal facilities.

These activities are directed by the chief of the branch with the aid of one principal assistant, a special engineer, and an Administrative Service Unit. This branch is composed of a Technical Staff Section, a Communication Section, a Laboratories and Shop Section, and three field sections.

The Assistant Branch Chief, in addition to his general duties, is specifically assigned to follow the activities of the Laboratories and Shop Section, the Technical Staff Section, and the Communication Section and to co-ordinate their activities with the field sections.

The Special Engineer serves as a technical staff specialist for the entire branch. He reviews technical reports, makes recommendations concerning the advisability of carrying on research work, assists and advises the Branch Chief and Assistant Branch Chief on special technical problems, initiates research projects, and is in charge of the general development and research work carried on by this branch.

The Administrative Service Unit is responsible for the operation of the Branch's stores group, for all clerical and accounting activities of the branch, and for preparation of the branch budget; for making special administrative studies; and for advising and assisting the branch chief in the general operation and administration of the branch.

The Laboratories and Shop Section is responsible for electrical laboratory tests, for the maintenance of primary and secondary standards of electrical measurement; for the calibration and repair of electrical instruments, relays, instrument transformers, portable test equipment, communication equipment, and other items which are sent in from the field or received from manufacturers or other sources and for conducting certain special tests in the field on communication equipment and facilities. This section also tests rubber gloves and other protective equipment and performs miscellaneous work, such as marking instrument scales, engraving name plates, repairing timing and clock mechanisms, repairing or modifying various types of electrical and mechanical equipment, and performing numerous special tests and research. Much of the repair work is performed in a small shop which is operated as a part of this section. The Chemical Laboratory makes analyses of coal, ash, boiler feed water, lubricating and insulating oils, and other items. These tests and related studies are required for the proper operation and maintenance of the production and transmission system.

The Communication Section is responsible for reviewing and making recommendations and proposals for revision, changes, or additions to the Authority's system, for the review in detail of proposed modifications or additions to the communication system during the preparation of design specifications; and for the review and certification of communication

specification drawings prior to their release to the Power Construction Branch. This section is also responsible for co-ordinating the over-all operation and maintenance of the communication system and for the maintenance of services to facilitate these activities. This section develops maintenance and testing procedures concerned with the maintenance and operation of the entire communication system. It makes a continuous study of technical tests and maintenance and operating reports prepared by engineers of this branch and initiates studies and tests on communication matters and facilities. This section is further responsible for keeping abreast of technical developments in the communication field and the latest technique in the testing and maintenance of communication equipment and facilities.

The Technical Staff Section reviews technical reports and dawings on proposed changes, additions, or modifications in metering, relaying, and power equipment. It follows design plans, co-operates with the engineering sections and branches, and makes recommendations concerning the proposed changes, particularly with regard to metering and relaying facilities. This section is responsible for the technical direction of the engineer training programme operated in this branch, for the assembly and overall preparation of technical test manuals and technical training material and for keeping abreast of new developments in metering, relaying, insulation and resistance testing, and the up-to-date techniques of testing electrical power equipment. It also reviews technical test reports, initiates technical test procedures, and assists the branch chief in the co-ordination of the testing activities of the field sections.

The field sections are responsible for the planning, co-ordination, and execution of the field test activities carried on by the branch. This work is divided into three field sections on a geographical basis. The field testing and related maintenance work includes initial tests of new installations at periodic intervals to determine the need for adjustment and maintenance ; performance of the necessary adjustments and certain types of maintenance in the more complex instruments and relays, emergency testing as required to locate the correct failures or sources of faulty operation in order to restore equipment to service, and a variety of special field tests involving the use of electrical instruments and specialized technical knowledge. The equipment includes watt-hour meters, switch-board indicating and graphic instruments, control and protective relays, power equipment, such as generators, governors, induction step-type and generator-type voltage regulators, transformers, oil circuit breakers, and instrument transformers, carrier current communication and relay system, load and frequency control equipment, telemetering equipment, and wire communication equipment, such as dial and manual telephone switch-boards, annunciators, repeaters, and remote control and supervisory equipment. The field sections are responsible for the work of the entire field test organization and for the co-ordination of all testing activities with construction and maintenance work to meet operating requirements in their particular areas. They are responsible for making recommendations towards maintaining and training the organization necessary to carry on the work and for furnishing representatives to discuss with representatives of other organizations on technical testing matters affecting their areas. The sections prepare detailed technical reports on work performed and make recommendations to improve test methods and procedures and to improve the operation, maintenance, or design of power facilities.

3.3.6. *Transmission System Maintenance Staff*.—The Chief of the Transmission System Maintenance Staff is responsible for generally supervising and co-ordinating the transmission maintenance activities. The work in the field is carried out by the district line and sub-station maintenance crews with the assistance of the system maintenance organization.

This organization determines the procedures and methods to be followed in the performance of the work and in the preparation and submission of reports. It also maintains records of equipment and files of technical data pertaining to transmission system maintenance. The organization is responsible for seeing that the maintenance programme is

understood and is being followed; that schedules are being maintained and that the quality of the work performed is satisfactory. It is also responsible for having available certain special equipment which is used by all districts as required but which is not available in sufficient quantities to permit permanent assignments to each district. The staff gives attention to the re-use and salvaging of retired material to keep the purchase of new material at a minimum.

The Transmission System Maintenance Staff is responsible for inspection of all poles on the transmission and communication systems. There are more than 75,000 poles which must be inspected about every three years, requiring that 25,000 poles to be inspected annually. On the basis of these inspections the necessary replacements are made and in most cases the completed work is checked in the field by a system representative.

The Transmission System Maintenance Staff studies new methods for expediting the location of line faults and studies line service interruptions with a view to recommending changes for improving service. These changes include such items as improvements in the grounding system to reduce lightning interruptions, replacement of insulators having undesirable service characteristics, replacement of conductors having insufficient mechanical strength or load capacity, etc. It studies and investigates all accidents to determine and eliminate the cause.

The Transmission System Maintenance Staff inspects all new lines and passes on final acceptance for operation. It carefully studies in advance the line outages required for construction in order to keep service interruptions at a minimum. It co-ordinates construction of temporary facilities, last-minute changes in construction plans, substitution of equipment, etc., to facilitate and keep on schedule the commissioning of new lines.

The Sub-station Maintenance Section of the Transmission System Maintenance Staff is responsible for similar activities in connection with the maintenance of sub-stations. The Sub-station Maintenance Supervisor keeps in touch with the actual conditions at all sub-stations and co-ordinates the maintenance activities with the field maintenance organizations.

The design and use of special transportation equipment is co-ordinated with the Transportation Section and maintenance personnel who will use this equipment. The development and use of special tools and test equipment is co-ordinated by this section. Maintenance schedules are periodically reviewed to determine frequency and most economical methods of performing maintenance work on various types of equipment. The number of operations of oil circuit breakers and regulators is tabulated on a continuing record to determine when it is necessary to overhaul this equipment.

The use of the portable sub-station is co-ordinated and scheduled by this section to obtain the maximum benefit from this equipment. Records are maintained on all major sub-station equipment. These records include complete name plate data, service records, information on failures and repairs, and data on modernization and modification.

A record of spare bushings and replacement parts for breakers and other equipment is maintained so that the location of spare bushings and parts is readily ascertainable.

A visible Kardex record is in use to record results of dielectric, neutralization number and interfacial tension tests in such a manner that the information on deteriorated oil is readily available and recommendations can be made for the reconditioning of oil which has deteriorated beyond a pre-determined value.

All failures of major sub-station equipment are tabulated and analysed to determine the cause of the failure and, if possible, to take corrective measures to prevent a recurring failure due to the same cause.

Equipment being retired from sub-stations is reviewed to determine the necessity of complete overhaul in the shops. Surplus equipment which is to be sold or junked is reviewed to determine what parts should be salvaged for re-use on the system as spare parts in other equipment.

All major equipment being installed in sub-stations is inspected and checked by a member of the Sub-station Maintenance Section to determine that the installation and performance of the equipment meets specifications. All work orders, job orders, and specification and sub-station drawings covering the rehabilitation of old sub-stations or the construction of new sub-stations are reviewed and commented upon or approved.

The Transmission System Maintenance Staff supervises the maintenance of all telephone and cable lines utilized for power operations. These lines are of several types : telephone lines underbuilt on transmission lines and requiring special protective equipment, land lines constructed on separate poles and private rights-of-way, and cable circuits of various types which carry telemetering, pilot wire, and remote control circuits to sub-stations.

The staff sets up the policies and procedures for the high standard of maintenance required to ensure continuity of communication service. It schedules periodic routine inspections of pole lines, cables and terminal equipment and submits recommendations for changes to improve service. It comments on and approves specifications and work orders for additional lines and equipment. Upon completion of construction, the staff inspects new lines for acceptance before they are placed in operation. The staff maintains complete records of poles and equipment installed in the communication system.

The Transmission System Maintenance Staff supervises the installation and maintenance of the fixed and mobile radio equipment used by the Division of Power Operations. It makes studies to determine the need for additional radio equipment and investigates complaints of radio interference which may originate on the transmission system.

The staff frequently checks the material stored at various warehouses for the maintenance of communication and radio equipment to ensure that sufficient quantities are on hand for emergency use.

The Transmission System Maintenance Staff assists in the scheduling, budgeting, and planning for right-of-way clearing, undergrowth control, and tree trimming on transmission and telephone line rights-of-way and recommending the methods, equipment, and personnel requirements for this work.

It prepares a tentative schedule several months before the beginning of each fiscal year, for which a budget estimate is submitted. It decides on crew locations and organizations with approximate starting dates. It co-ordinates the employment of crews, employment contracts, transportation and other equipment requisitioned through the Transmission System Maintenance Staff. The crews then begin work under the direct supervision of the area operating superintendents.

It keeps records of all right-of-way maintenance in the office, from which cost analyses for various methods and conditions are made from time to time. The costs and results of a chemical clearing programme are receiving major emphasis, and in addition to this programme, field experiments are carried out by the Transmission System Maintenance Staff to test and evaluate new methods of chemical control.

4. The Bonneville Power Administration.

As a marketing agent for the energy produced at the Federal Dams the Bonneville Power Administration plays a vital role in the Pacific North Wests' Power Programme. The Bonneville Power Administration sells bulk power to private and publicly owned utilities for distribution to their consumers. It also markets large blocks of power to industrial customers and to federal establishments including the Atomic Energy Commission.

In performing its marketing function, the Bonneville Power Administration builds, maintains and operates a region wide net-work of transmission lines and related facilities, covering an area of about 200,000 square miles. The transmission system comprises of 5,445 miles of lines which carry to markets power from Bonneville, Grand Coulee and Hungry Horse power plants and permits the close integration of Federal plants with each other and with other generating facilities in this region so as to.—

(*a*) make the fullest use of low cost hydro power and increase production through co-ordinated operation ;

(*b*) maintain reservoir levels at non-federal generating plants by using surplus stream flow energy ;

(*c*) keep the output of higher cost thermal electric energy to a minimum consistent with serving all loads ;

(*d*) permit maximum use of the most efficient thermal plants, when thermal generation is necessary ; and

(*e*) increase the reliability of service throughout the region by providing emergency inter-connections between the federal system and the other utility systems.

The Bonneville Power Administration network is the backbone of the North-West Power Pool which includes non-federal as well as federal facilities.

Power generated at Bonneville and Grand Coulee Power Plants for the Administration exceeded 18·5 billion units during 1952. This was more than 60 per cent of all power produced in the Pacific North-West during that year. Energy sales to consumers of the Bonneville Power Administration exceeded 17 billion units during the year.

The system peak recorded with a coincidental demand on Bonneville and Grand Coulee plants was 2,784 megawatts.

Over three-fourths of the energy sales during the year were made at an average rate of 2·09 mils per Kilowatt-hour to industries operating at high load factor and to utilities having substantial generating facilities.

Customers served by the administration at the end of 1952 totalled 112 including 76 publicly owned distributors, 16 industrial consumers, 12 federal agencies and 8 privately owned utilities.

5. The Rural Electrification Administration.

The R.E.A. is a federal organization that gives loans to co-operative societies established for promoting rural electrification, on non-profit basis.

The R.E.A. works hand-in-hand with co-operative leaders with the basic principle that its aid should be given in such a way as to promote the ability of the co-operatives to handle their own affairs effectively, with less and less assistance from the Government in the long run.

Rural electrification as a programme of the Congress was established by President Roosevelt in 1935. The executive order created a Rural Electrification Administration with powers in an administrator to " initiate, formulate, administer and supervise a programme of approved projects for the generation, transmission and distribution of power in rural areas ". The authority act had made $100,000,000 available to the President for allocation to the R.E.A. activities. As then provided, it was to execute a 10-year programme promotion by making interest bearing loans (2 per cent) repayable in not more than 25 years, to local interests so organized, as to make them eligible borrowers of public fund ; preference to be given to public bodies and to co-operative, non-profit and limited-dividend associations organized under State laws.

As a participant in a programme of relief from unemployment, the immediate task of the R.E.A. was to promote rural electrification in such a manner as to get funds rapidly into channels of commerce and thereby stimulate employment both in the construction of new electric lines and in the production by suppliers of poles, conductors, transformers and other essential materials.

Two principal problems confronting a group of farm people deserving to become eligible for a loan for the construction of a local electric distribution system were—

(*a*) Proper incorporation and organization under State law ;

(*b*) Demonstration that their project could operate successfully and repay the loan within the period originally set at 20 years and later on increased to 35 years.

These two major problems involved many component problems,—

(i) retaining of legal counsel and direction in incorporation and organization ;

(ii) election of directors and officers in a manner prescribed by law ;

(iii) enlisting the interest and signing up of prospective members ;

(iv) design of the system by competent engineers ;

(v) arrangements for a source of wholesale power at a reasonable rate ;

(vi) calculation of revenues, costs of construction and operation and retirement of debt and

(vii) where after initial calculations, pay out feasibility is not evident, the procurement of additional members, re-design of the system and finally development of a relationship among revenues, costs and amortization of debt that indicates feasibility.

Between 1937 and 1939 the R.E.A. developed an organization and procedure that would enable it to go into the field and guide the applicant's activities from their beginning. Gradually, the R.E.A. assumed the responsibility of sending to farm-people desiring electricity and requiring loans, various types of specialists who could advise them on such matters as effecting a legally adequate organization, securing an initial and expanded membership, designing a suitable system, negotiating with sources of wholesale power, securing certificates of necessity and rights-of-way, standing for their rights in conflicts with commercial companies before commissions and legislatures and, when legislative authority was indefinite, introducing appropriate Bills in legislatures.

In July 1939, under the reorganization plan, the R.E.A. ceased to be an independent agency and became a part of the department of agriculture, although its administrative integrity was retained. This move promoted more intimate contacts with other agencies concerned with the welfare of farmers and under-scored the basic concept that rural electrification is not merely a matter of mechanical technology, but is a social force helping to mould the culture of rural life.

During the war period, R.E.A. became temporarily converted by circumstances from an agency promoting the normal construction of rural lines to one aiding borrowers, to concentrate construction and use of materials on military, war industry and food production needs. Among military needs were connections to provide power and light to air beacons, army camps, and navy installations and supply of energy for the production of aluminium required for the large-scale production of airplanes.

The R.E.A. organization has the following two divisions :—

(1) Loan Division.

(2) Auxiliary Division.

(1) *Loan Division.*—The loan divisions which have direct relations with borrowers are—

(*a*) *The Applications and Loans Division* for recommending loans to the Administration and for guidance to borrowers in preparatory steps.

(*b*) *The Engineering Division* responsible for the approval of the design of borrower's systems, inspection of construction, and final inspection and approval of the properties that are the security for the loans.

(*c*) *The Management Division* responsible for advice and assistance to borrowers in respect of their operating and general management problems.

(*d*) *The Finance Division* responsible for audits and accounts of borrowers, receipts of payments, advance of funds and the accounting for transactions with the treasury, other Government agencies and borrowers.

(2) *Auxiliary or consulting or service divisions.*—These are—

(*a*) *The Administration Services Division* responsible for communication and records, administrative accounting, travel, property and space, operating records and statistical services.

(*b*) *The Information Services Division* for publications, press and radio service and co-operative education.

(*c*) *The Personnel Division* responsible for employment of R.E.A. personnel, classification, training, safety and health and personnel records.

(*d*) *Technical Standards Division* for the establishment of electric construction and use standards, electro-agriculture, and new developments.

Attached to the Administrator's Office is a staff responsible for programme analysis, organization, procedures, budget and various problems concerned with the activities of borrowers, requiring high level attentions.

In 1948, there was added the Power Division, a line division responsible for inspection and provision of technical assistance in the design, construction and management of generation plants and transmission lines, a development made necessary by increase of borrower's problems arising out of power shortage.

R.E.A. borrowers are private enterprises just as much as are the commercial companies. Besides the fundamental difference in motivation (viz., service or profits), the other main difference is that R.E.A. borrowers receive investment funds from and are influenced by a public money source, while the commercial concerns receive investment funds from and are influenced by the private money-market.

In the early period, when the co-operatives were young, inexperienced, and struggling against obstacles, it had been necessary to give advice and assistance to all of them and in considerable detail both in their interests and in the interest of security for the Government loans.

By 1945, however, a number of borrowers had 7 or 8 years experience and accordingly there was a transition to a new policy of advice and assistance. Visits, inspections, audits, advice and assistances of the R.E.A. field staff were put on a selective basis, regularly to new co-operatives and to older ones whose financial struggles still gave concern and on request to others. Requests for assistance did not cease, because new problems on a higher level—rate of adjustments, increase of capacity and so on—were filling the place of earlier simpler problems.

Thus these independent business enterprises were thrown more and more on their own and the R.E.A. was able to stretch its limited man-power over a large volume of lending, supervision of design and new construction and major problems of co-operative management.

Another consequence of emphasis on co-operatives as private enterprises was more serious development of activities of broadly educational character, looking towards the time when borrowers would have amortized their loans become free of creditor-debtor influences and be completely on their own.

Accordingly, through R.E.A. publications—" Rural Electrification News " and Special bulletins—public addresses on occasions by R.E.A. officials in co-operation with State associations of co-operatives organized by themselves, and regional conferences of directors and manager promoted by R.E.A., increasing attention came to be given to problems of co-operative organization and to procedures of efficient management.

Supplementing Co-operatives' State Associations is the National Rural Electric Co-operative Association with offices and a well-organized staff in Washington, a constructively influential institution organised by borrowers and administered independently of R.E.A.

The R.E.A. borrowers' retail rate schedules have always been so constructed as to yield revenues not only to cover costs of operation, maintenance and replacement, but also to provide funds required by the schedule of loan repayments.

The co-operatives do not pay any income-tax because they are non-profit co-operative bodies and have no base to which to apply such a tax. But, in the matter of property and other local taxes, they carry their share as required by the laws of the State.

The progress of rural electrification, in the number of farms connected, the quantity of electricity consumed, range of uses, and influence on the rural economy, is modifying progressively the problems and objectives of R.E.A. Measured only in terms of farms remaining to be connected, the R.E.A. programme is three-fourths completed. The final one-fourth of this particular phase of the programme will not be achieved easily, because the remaining farms are in localities of relatively lower density, lower income, and calculations of economic feasibility become correspondingly difficult. Suggestions have been made that, in order to bring electric service more promptly to these areas on an economically feasible and self-liquidating basis, the period of amortization of R.E.A. loans for the construction of the facilities required for these areas should be on a 50-year basis.

Notwithstanding federal development of large hydro resources and plans for new generating facilities by commercial companies, many borrowers will not be within the economical reach of such power. Many of them will have to make individual or group investments in facilities for basic energy of their own generation and transmission.

In October 1949, President Truman issued an order amending the Rural Electrification Act of 1936, to provide for a rural telephone loan programme. By making federal credit available on a self-liquidating basis and on liberal terms, 2 per cent interest and 35 years amortization period. Local private enterprise was assisted in providing an essential rural telephone service available on the same basis for all persons in a rural service area.

Within the limits of available administrative funds, an equitable balance was arrived at in the emphasis given to the electric and telephone programmes.

It has been the policy of the R.E.A. to have electric borrowers assume an increasing amount of responsibility for the management and operation of their systems as they gained maturity and experience. A substantial shift in this direction appeared desirable in order to make R.E.A. personnel available for the telephone programme.

The loan divisions which had been administering the electric programme were abolished and five electric Distribution Area Offices established to provide a single point of contact with R.E.A. for electric distribution borrowers. These offices are headquartered in Washington and have complete responsibility for relationships with electric distribution borrowers in their respective areas. All loan and engineering responsibilities for power type borrowers were centralized in a single division.

In 1952, the R.E.A. approved rural electric loans amounting to more than $165,000,000 and made loan allocations of slightly over $41,000,000 to rural telephone borrowers. Approximately, 6,000 miles of new lines and 73 central offices to serve more than 23,000 rural subscribers were in construction during the year 1952.

By June 30, 1952, 88·1 per cent of the United States of America farms were receiving central station electric service. R.E.A. borrowers were serving actually a total of 3,769,426 rural consumers of which 2,534,998 or about 67 per cent were classified as farms (i.e.) the R.E.A. borrowers were serving in 1952 about 53·5 per cent of all farms served.

The financial position of the electric borrowers continued to be strong. By the end of 1952, the borrowers had repaid a total of $361,898,705. There were about 1,080 borrowers in 1952.

The R.E.A's. policy was always to establish a nation-wide programme which eventually would stand on its own feet. The aim has been to develop independent rural electric system each of which would take its place in the particular rural economy in which it is located as a healthy, locally owned and managed business enterprise. Each borrower is an entirely independent co-operate body locally owned and controlled and subject to applicable State laws.

The rural electric systems have matured over the past 17 years as anticipated. Backbone distribution lines have been provided for more than, 3,769,000 of the nation's farms and other rural consumers. The average electric co-operative has become a $2,000,000 local non-profit enterprise.

Approximately 80 per cent of the total R.E.A. electrification loans up to 1952, have been loaned for the construction of distribution systems ; 18·9 per cent for generation and transmission and the balance for consumers facility loans.

The R.E.A. borrowers had a total of 591,357 KW. of generating capacity in operation by 1952 and of this 300,750 KW. was steam, 254,466 KW. was internal combustion and the balance of 36,141 KW. was hydro.

Consumption of power by farmers served by the borrower's system was 146 K.W.H. per month in 1950 and 165 K.W.H. per month in 1951.

6. The British Electricity Authority.

6.1. *History and outline of organization.*—In Britain because of the basis on which the rights of supply was originally granted, the electrical industry was for many years confined to small units operated by local authorities and companies generating and distributing within their limited areas at varying frequencies. Gradually the need for expansion was appreciated and power companies for operation in several large areas and to generate in bulk came into being. During World War I, the limitations of the existing organization were realized and in 1919 the Electricity Commissioners were appointed for the co-ordination of undertakings. The desired results, of co-ordination of undertakings were not, however, forthcoming and a further step was taken in 1926 by establishing a Central Board to co-ordinate the generation side of the undertakings and provide the main transmission inter-connection between major power stations which then became known as the ' British Grid '. For this purpose, it was necessary to standardize the frequency of supply throughout the country.

The ownership of power stations and the distribution of electricity still however remained in the hands of separate undertakings numbering over 500.

After the World War II nationalization of the electrical industry effected full co-ordination of electricity supply throughout Great Britain with the exception of that part of Scotland administered by the North Hydro-Electric Board.

Under the Electricity Act, 1947, the British Electricity Authority (the Central Authority) and 14 Area Electricity Boards took over on 1st April 1948, the ownership and operation of the electricity supply industry, throughout Great Britain except the North of Scotland District and some small non-statutory electricity supplies amounting to a fraction of one per cent of the total supplies to the public. This was done to develop and maintain efficient, co-ordinated and economical systems of electricity supply throughout Great Britain.

The Central Authority are a Statutory corporation and their members who include four Area Board Chairmen are appointed by the Ministry of Fuel and Power. The Authority are responsible for the generation of Electricity and its supply in bulk to the Area Boards for the purposes of distribution and they also exercise a general control over the policy of the Boards. The authority took over the power stations and associated main transmission lines, which belonged to the former Public authority and company undertakings, together with the national net work of main transmission lines which was owned and operated by the Central Electricity Board. For the local management and operation of the power stations and the grid, the Authority divided the system into 14-generation divisions, the areas of which correspond in general to those of the Area Boards.

The fourteen Area Electricity Boards are also statutory corporations whose members are appointed by the Minister of Fuel and Power. They are responsible for planning and carrying out the distribution of electricity to the consumers and for this purpose, took over the distribution networks of 540 electricity undertakings. The Area Boards obtain their supply of Electricity from the Authority and deliver it to the distribution systems of the Boards either directly from the power stations or from other points in the Grid. Associated with each Area is a consultative council representing consumer and general public interests whose members are appointed by the Minister of Fuel and Power.

These arrangements cover the whole of England, Wales and Scotland except the North of Scotland District, where the North of Scotland Hydro-Electric Board are responsible for generation, transmission and distribution of electricity under the Hydro-Electric Development (Scotland) Act, 1943, as amended by the Electricity Act, 1947.

6.2. *Generation.*—On 31st March 1953, the Authority owned 285 power stations with a total installed generating capacity of 17,155 megawatts and a total output capacity with all plant in service of 15,535 megawatts.

The following table shows the total installed capacities of generating sets of various types at various classes of stations, and the total installed and maximum output capacities of each class of station, as on 31st March 1953 :—

Class of power stations.	Installed capacity of generation sets.				Maximum output capacity of stations.
	Steam plant.	Hydro-plant.	Internal combustion engine plant.	Total.	
(1)	(2)	(3)	(4)	(5)	(6)
	MW.	MW.	MW.	MW.	MW.
Steam	16,900	..	2	16,902	15,302
Hydro	..	172	2	174	171
Internal combustion engine ..	..	..	69	69	52
Waste heat	10	..	..	10	10
Total ..	16,910	172	73	17,155	15,535

Because of the shortage of generating plant, many generating sets and boilers which are old, small and expensive to operate are retained in operation. More than two-fifths of the steam driven generating sets representing 15·2 per cent of the total installed capacity of such sets and more than two-fifths of the boilers representing 13 per cent of the total boiler capacity, are 25 years old or more.

Seven new power stations were brought into commission during 1952–53. Six of the new stations operate at a steam pressure at the turbine stop valve of 900 lb. per square inch and the seventh at 700 lb. per square inch. In all cases except one (where the fuel is oil), the boilers are fired by pulverised coal. All stations have river or sea water for cooling except one where cooling towers are used.

The capacities of new plants installed were as follows :—

Generating capacity 1,478 megawatts.

Boiler capacity 18,435,000 lb. per hour.

Maximum output capacity 1,423 megawatts.

The bulk of the plant in current programmes consist of standard 30 MW turbo sets with steam conditions of 600 lb. per square inch and 850°F at the turbine stop valve and 60 MW sets with steam conditions of 900 lb. per square inch and 900°F. The programme for 1958 which was approved during 1952–53 includes six sets of 30 MW and nine of 60 MW together with a 120 MW set.

The standard 30 and 60 MW sets are coming into service in increasing numbers. The generators of some of these sets are the first in United Kingdom in which hydrogen is used as a cooling medium. They are run with a hydrogen pressure of ½lb. per square inch above atmospheric pressure but this is being raised to 15 lb. per square inch in certain new designs.

Higher steam pressures and temperatures are being adopted in many countries and by the Authority. In the United Kingdom, however, there are special technical difficulties due to the qualities of available coals. Many of the coals have a high ash content and some, particularly from the increasingly important East Midlands coalfield, also contain appreciable quantities of chlorides. The presence of sodium and potassium salts is very liable to cause severe trouble through the formation of "bonded deposits" on the heating surfaces of the boilers, and this condition is aggravated by higher steam conditions and the consequent higher metal temperatures in the superheater zone. Progress in the design of this plant is, therefore, pursued with caution. The mechanism of the aggregation of deposits is complex and not yet fully understood, but research is being pursued by the Authority and by others concerned with the problem.

The new plant with higher steam conditions on which firm design work was started during the year included that intended for the Willingdon A station, near Derby, which will employ a 1,500 lb. per square inch 1,050 degrees Fahrenheit "straight" cycle utilizing 100,000 kilowatt units, and that intended for two new stations, Blyth and Drakelow B (Burton-on-Trent), which will employ 120,000 kilowatt units on the reheat cycle, with steam at 1,500 lb. per square inch 1,000 degrees Fahrenheit reheating to 1,000 degrees. Each turbo-generator set will be supplied by single boiler which, in the case of the two latter stations, will be rated at 860,000 lb. of steam per hour.

The total quantity of electricity generated at power stations owned by the Authority in 1952–53 was 61,603 million units. The total quantity of electricity sent out from the stations was 57,951 million units.

Out of the total production, over 99 per cent was by steam, the production by waste heat, hydro and internal combustion being less than one per cent.

The average overall thermal efficiency was 22·72 per cent and average works cost per unit sent out 0·545 d. The total quantity of fuel used during 1952–53 was 35·7 million tons.

6.3. *Main Transmission.*—The Authority's main transmission system comprised of 4,682 route miles (6,471 circuit miles) of overhead lines and underground cables as follows as on 31st March 1953 :—

Types of lines.	Route miles of lines. 132 KV.	66 KV or lower voltages.	Total.
Overhead	4,107	140	4,247
Underground	67	368	435
Total ..	4,174	508	4,682

During the year 1952–53, there was a net increase of 83 route miles comprising 69 miles of 132 KV lines and 13 at 66 KV or less.

The first section of the supergrid, 41 miles of single circuit 275 KV line between Staythorpe and West Melton was in operation during the year at 132 KV. On the Tilbury-Elstree line were erected the first 275 KV double circuit towers with twin 0·4 square inch conductors per phase suitable for conversion to 380 KV.

On 31st March 1953, there were 299 Grid sub-stations, with a total transformer capacity of 18,939 MVA.

6.4. *Operation.*—The national maximum potential demand in 1952–53 was 14,850 megawatts. The load factor over the year based on the maximum demand supplied was 49·2.

6.5. *Consumers.*—At 31st March 1953, the number of consumers connected to the Area Board Systems was 13,884,760. Number of consumers and units sold are as follows :—

Types of Consumer.	Number of consumers.	Units sold (millions of units).
Industrial	157,713	25,879
Commercial	1,385,159	7,554
Farm	134,429	674
Domestic	12,203,284	16,260
Traction	70	1,400
Public lighting	4,105	497
Total ..	13,884,760	52,264

6.6. *Rural Electrification.*—Total farms connected up to 31st March 1953 were 134,429. 10,584 farms were connected up in 1952–53. The average consumption of electricity per farm was 5,011 units during 1952–53.

B. POWER STATIONS

GENERAL.

The following were the important Generating Stations visited in the various countries :—

I. CANADA.

(a) *Shawinigan Water and Power Company*—
(i) Rapide Blanc Power House.
(ii) Trenche.
(iii) La Tuque.
(iv) Grandmere.
(v) Shawinigan Falls 2 and 3.
(vi) La Gabelle.

(b) *Quebec Hydro Commission and Aluminium Company of Canada*—
(i) Beauharnois Power Development.
(ii) Shipshaw Power Development.
(iii) Isle Maligne Hydro Electric Power Station.
(iv) Chute Du Diable.
(v) Chute Savanne.

(c) *Ontario Hydro-Electric Power Commission*—
(i) Niagara (No. 2).
(ii) Queenston Power House.
(iii) Ontario Power Station.
(iv) Decew Falls.
(v) Stewart Ville.
(vi) Des Joachims.
(vii) Chenaux.
(viii) Chatsfalls.
(ix) Pine Portage.
(x) Aguasabon and the following steam station :—
(i) Richard L. Hearn Generating Station.
(ii) J. Clark Keith Generating Station.

II. UNITED STATES OF AMERICA.

(a) *Tennessee Valley Authority*—
(i) Apalachia.
(ii) Chickamauga.
(iii) Fontana.
(iv) Guntersville.
(v) Norris.
(vi) Wheeler.
(vii) Wilson.
(viii) Kentucky.
(ix) Fort Loudoun.
(x) Ocoee No. 3.
(xi) Wattsbar.
(xii) Hales Bar.
(xiii) Douglas.
(xiv) Cherokee.

(b) *Bureau of Reclamation*—
(i) Hoover Dam Plant.
(ii) Hungry Horse Dam.
(iii) Davis Dam Project.
(iv) Columbia Basin Project (Grand Coulee).
(v) Pole Hill Power Plant.
(vi) Flat Iron Plant.
(vii) Green Mountain Plant.

III. UNITED KINGDOM.

(i) Pitlochry (Scotland).
(ii) Loch Sloy (Scotland).
(iii) Tummel (Scotland).
(iv) Errochty (Scotland).
(v) Clunie (Scotland).
(vi) Maentwrog—Merryside (North Wales) and the following steam stations—
(i) Carrington.
(ii) Littlebrook (A, B and C).
(iii) Battersea.
(iv) Hartshead.
(v) Stourport.
(vi) Cliffquay.
(vii) Fulham.
(viii) Doncaster.
(ix) Kearsely (A, B and C).
(x) Dunston.
(xi) Brom-borough.
(xii) Partishead.
(xiii) Stay thorpe.
(xiv) Meaford.

IV. SWEDEN.

(i) Harspranget.
(ii) Porjus.
(iii) Ligga.
(iv) Kelforsen.
(v) Nowforsen.
(vi) Trollhattan.

1. The Shawinigan Water and Power Company

1.1. *General.*—The Shawinigan Water and Power Company, the pioneer electrical concern in the Province of Quebec, Canada, utilizes the total fall of about 640 feet in the 80 miles section of the St. Maurice River for the production of electrical energy which they transmit and distribute to a territory covering an area of 20,000 square miles.

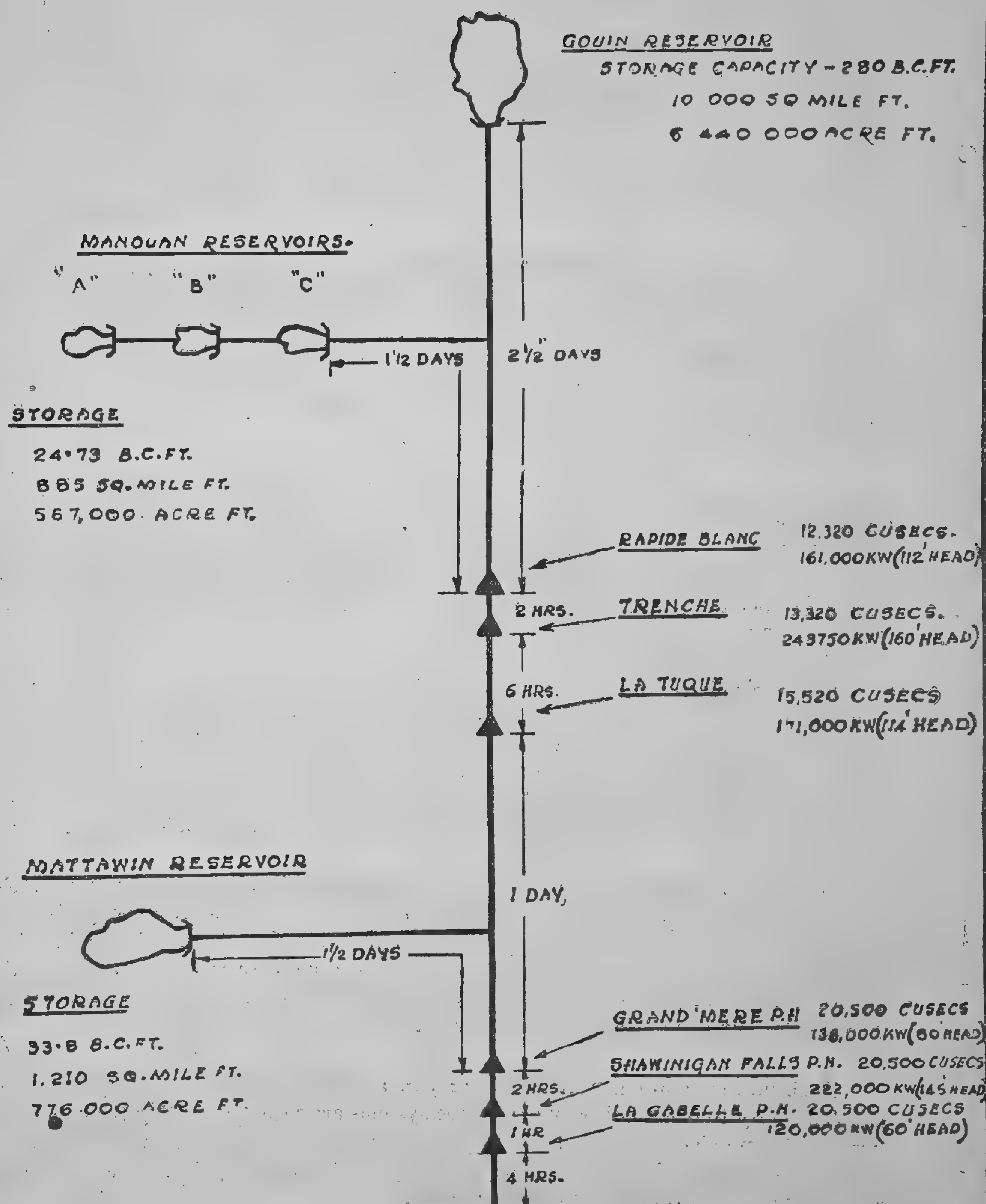
The power company owns storage reservoirs whose capacities total to about 383 billion cubic feet. The lake formed by the Gouin Dam at the head waters of the St. Maurice River covers an area of about 600 square miles and drains a water shed of 3,300 square miles. The regulation has increased its maximum flow at the Shawinigan falls from 6,000 to 20,200 cusecs.

Water distribution at various Power Plants on the St. Maurice River during the regulating season—July to March inclusive.

Average run-off 0·94 *c.f.s./square mile.*

	C.F.S.
In-flow to Gouin Dam (3,310 square miles)	3,110
From storage (71·73 billion cubic feet)	3,040
Flow from Gouin Dam	6,150
Uncontrolled run-off Gouin—Allard (1,738 square miles)	1,630
Inflow to Manouan Dams (1,172 square miles)	1,090
From Manouan Dams storage (24·93 billion cubic feet)	1,050
Flow at Allard development	9,920
Uncontrolled run-off Allard-Du Lievre (10 square miles)	10
Flow at Du Lievre development	9,930
Uncontrolled run-off Du Lievre—Des Coeurs (246 square miles)	240
Flow at Des Coeurs development	10,170
Uncontrolled run-off Des Coeurs—R. Blanc (1,574 square miles)	1,450
From Rapide Blanc storage	700
Flow at Rapide Blanc development	12,320
Uncontrolled run-off Rapide Blanc—Trenche (1,050 square miles)	1,000
Flow at Trenche development	13,320
Uncontrolled run-off Trenche—Sansnom (1,035 square miles)	900
Flow at Sansnom development	14,220
Uncontrolled run-off Sansnom—La Tuque (1,433 square miles)	1,300
Flow at La Tuque development	15,520
Uncontrolled run-off La Tuque—Grand'mere (2,239 square miles)	2,080
Inflow to Mattawin Dam (1,595 square miles)	1,490
From Mattawin Dam storage (33·5 billion cubic feet)	1,410
Flow at Grand'mere development	20,500

Sketch P.S. 2 gives the water distribution at various power plants during the regulating season.



SKETCH OF
ST. MAURICE RIVER

SKETCH. P.S. 2.

Storages are provided during the course of the river fall and power developed at Rapide-Blanc, Trenche, La Tuque, Grand'mere, Shawinigan and La Gabelle, the first three being in the upper Maurice River and the last three in the lower Maurice River.

The Shawinigan Power System is interconnected with the St. Lawrence River plants of the Quebec Hydro and the Saguenay River plants of the Aluminium Company of Canada; the Quebec Hydro Commision has two plants with a total installed capacity of about 1,320,000 h.p. and on the other side lies the Saguenay river plant of Aluminium Company of Canada with a capacity of about 1,320,000 h.p. The Shawinigan Water and Power System with their present installed capacity of about 1,600,000 h.p. is situated between these two systems and is inter-connected with them through high voltage ties and operated to a large extent as one unit. These systems have different river flows and load characteristics.

The generating plants of the Quebec Hydro are situated on the St. Lawrence River, which like the Mississippi just keeps rolling along. The great lakes act as enormous natural storage reservoirs which smooth out the flow of the St. Lawrence at Montreal so that the possible generation of power is constant, except during the peak load months in the winter, when ice problems tend to reduce the capacity just when it is most needed. The average mean flow is 220,000 cusecs, the maximum and minimum recorded flows being 318,000 cusecs and 173,000 cusecs respectively.

The Quebec Hydro Commission serving the Metropolitan areas of Montreal and its surroundings is typical of such stations serving most metropolitan areas with heavy peak demand during winter months and a decided dropping off in demand during summer months. During nights and week ends, the demand is low. Thus a tremendous amount of power and energy is available in the Quebec Hydro System during week ends, nights and for most of the summer months.

The Shawinigan System has an excellent storage capacity to store the spring flood water brought about by melting snows and occasional freshes during surplus water conditions in the river. They store water in the summer months, utilizing the offpeak energy available from the Quebec Hydro System. During winter, when the water shed is frozen up, the normal run off is drastically reduced and it is then they draw heavily on their storage reservoirs to maintain the river flow at the plants at the required figure.

In regard to the Aluminium Company's installation in the Saguenay region, their characteristics are generally similar to those of the Shawinigan, but there is enough difference to enable them to help each other. For example the high water conditions for Aluminium Company occur some two weeks later and their storages are more adequate than Shawinigan and they have greater machine capacity than water which enables them to help the Shawinigan in times of peak demand.

In short, the Shawinigan, the Quebec Hydro and the Aluminium Company's plants are supplementary to one another and the three systems are together meeting the demand for power in the province of Quebec. At the beginning of the World War II, the three systems were inter-connected in order to take advantage of the diversity in load and hydraulic conditions and they continue to operate as such.

Demand.—The installed capacity of the Shawinigan Water and Power Company is of the order of 1,400,000 h.p. In addition, they buy power to the extent of 100,000 h.p. from Saguenay Power Company and have recently contracted for an additional power of about 50,000 h.p. commencing from 1st January 1954, from this company. They also buy power to the extent of 50,000 h.p. from the Quebec Hydro Commission.

The company is carrying out a diversion into the Gouin Reservoir of the Mattawin River which now flows into the James bay and the addditional water running their 6 power stations on the St. Maurice river, will add about 27,000 h.p. to their existing capacity. The load has been increasing at about double the pre-war rate. This is now about 10 per cent per year, which if continued, will mean that the company will need new power to the extent of about 160,000 h.p. each year.

The Company's next power development will be at the Rapide Sans Nom, which will have a capacity of 290,000 h.p. This was programmed to be started in the spring of 1952 so as to commence operation late in 1954.

Summarising the above, the main features of the Shawinigan Water and Power Company are briefly as follows :—

The Company was founded in January 1898 and their assets now total 280 million dollars. Their present installed capacity is 1,600,000 h.p. as indicated below :—

	Head.	Present installed capacity.	Additional capacity proposed.
	FEET.	H.P.	H.P.
1 Rapide Blanc	112	200,000	40,000
2 Trenche	160	325,000	65,000
3 La Tuque	114	222,500	44,500
4 Grand'mere	80	200,500	25,000
5 Shawinigan Falls 2 and 3	145	416,500	..
6 La Gabelle	60	172,000	..
7 St. Norcisse	156	22,000	..
8 St. Alban	69	4,000	..
		1,562,500	174,500

Power purchased under long-term contracts—150,000 h.p.

The following are the undeveloped sites likely to be taken up later :—

	Head.	Capacity.
	FEET.	H.P.
1 Rapide Allard	87	132,000
2 Rapide Du Lievre	83	124,000
3 Rapide Des Coeurs	70	112,000
4 Rapide Sans Nom	110	252,000
		620,000

The main features of the generating units at the various power-houses are given in Table 1.

Table 1.—*The Shawinigan Water and Power Company Generating Units.*

Number.	Rapide Blanc.	Trenche.	La Tuque.	Grand Mere.	Shawinigan No. 2.	Shawinigan No. 3.	Lagabelle.	St. Norcisse.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1 Date of installation ..	4 Nos.—1934. 1 No.—1943.	1951	4 Nos.—1940 1 No.—1943	1915 1916 1930 2 Nos.—1941.	2 Nos.—1911. 2 Nos.—1914. 1 No.—1913. 1 No.—1922. 2 Nos.—1928.	1948	4 Nos.—1924 1 No.—1931.	1926
2 Discharge in cusecs.	12,320	13,320	15,520	20,500	20,500	20,500	20,500	1,680
3 Water wheels—								
(*a*) Maker's name and country.	Dominion Eng. Company of Canada.	(. . . . . . Allis Chalmers and Dominion Engineering Company of Canada . . . .)						
(*b*) Type	(. . . . . Francis reaction vertical . . .)				5 Francis horizontal 3—Vertical.	2 Francis vertical.	Fixed blade propeller.	Francis vertical.
(*c*) Horse-power of each wheel.	40,000	65,000	48,000	7–22,000 2–24,500	..	65,000	36,000	11,100
(*d*) Head in feet	112	160	114	80	145	145	60	147
(*e*) Speed in RPM ..	109·1	128·6	112·5	120–7 units 112·5–2 ,,	5–225 3–138·5	120	120	180
(*f*) Number of sets installed.	5	5	5	9	8	3	5	2
4 Generators—								
(*a*) Maker's name ..	Westing-house.	G.E.	G.E.	Westinghouse.	5–Westinghouse. 3–G.E.	G.E.	Westinghouse.	Westinghouse.
(*b*) Capacity of each unit in KVA.	36,000	53,000	40,000	7–18,500 1–20,000 1–25,000	2–14,000 3–15,000 3–40,000	62,500	33,000	10,000
(*c*) Voltage of generation.	11,000	13,800	11,000	6,600	6,600	13,800	6,600	6,600
(*d*) Power factor	0·85	0·90	0·90	0·80	5–0·93 3–0·75	0·80	0·75	0·75
(*e*) Speed in RPM. ..	109·1	128·6	112·5	120–7 sets. 112·5–2 sets.	5–225 3–138·5	120	120	180
(*f*) Are damper windings provided.	(. . . Yes—non-continuous . .)					(Non-continuous.)		
(*g*) Frequency (cycles) ..	60	60	60	60	60	60	60	60
(*h*) Temperature rise above an ambient of 25°C.	60°C	60°C	60°C	60°C	50°C	60°C	68°C and maximum temperature 90°C.	70°C

TABLE 1.—*The Shawinigan Water and Power Company Generating Units*—cont.

Number.	Rapide Blanc. (1)	Trenche. (2)	La Tuque. (3)	Grand'mere. (4)	Shawinigan No. 2. (5)	Shawinigan No. 3. (6)	Lagabelle. (7)	St. Norcisse. (8)
5 Excitation System ..	(. . . .	Direct driven	. . . . .	. . . .)	Directly driven for 3 and Separately excited for 5.	(. . . Direct driven	. . . .	. . . .)
6 Pilot Exciters—								
(a) Capacity	25KW	12KW	10KW	(. None provided	. . . . .)	12KW	(. None provided	. . , .)
(b) Volts	250V	250V	250V			250V		
(c) Amps	100	48	40			48		
(d) Type	(. . . .	Compound wound	. . .)			Compound		
7 Main Exciters—								
(a) Capacity	325	270	250	150 for 18500 and 20000 KW sets. 240 for 25000 KW set.	1 to 5 sets—3 sets—400 KW 580 RPM. 2 sets—Water wheel driven and one motor driven. 6 to 8–212KW.	325	220	135
(b) Voltage	250V	250V	250V	250V	125V for 1 to 5 250V for 6 to 8	250V	250V	250V
(c) Amps	1300	1080	1,000	600	3,200 amps for 1 to 5. 850 for 6 to 8.	1,300	880	540
(d) Temperature rise above a normal ambient of 25°C.	50°C	40°C	40°C	40°C	6–8 sets 50°C		..	..
(e) Type	Shunt.	Shunt.	Shunt	Shunt	Shunt for 6–8 and compound for 1 to 5.	Shunt	Compound	Shunt.
8 Short circuit ratio	(. . . .	1·2 to 1·35	. . . . .)	1·2	..	..	..	..
9 Inertia constant	(. . . .	2·23 to 3·10	. . . . .)	..	..	..	..	..
10 WR^2 for the set in lb. ft.^{2}.	29×10^6	44×10^6	30×10^6	..	$4{\cdot}6\times10^6$ for 1—5 sets. 30×10^6 for 6—8 sets.	55×10^6	..	$2{\cdot}4\times10^6$
11 Run-away speed for 15 min.	1·9×normal speed.	..	1·8×Normal speed.	1·7 times speed.	..	1·8 times normal speed.	..	1·8 times normal speed.
12 Speed rise when full load is thrown off.	30 per cent.	35·5 per cent.	35 per cent.	..	42 per cent.	39·3 per cent.	..	40 per cent.
13 Speed drop when full load is thrown on	42 per cent.	56·5 per cent.	Very high.	..	..	70 per cent.	..	..

Summary of Discharges, Head and Units generated per day on a week day.

	Average discharge in cusecs.	*Average discharge per unit in cusecs.*	*Units generated per day.*	*Average head.*
			MWH	FT.
Rapide Blanc	12,600	..	2,593	109·53
Trenche	15,545	4,075	4,503	162·00
La Tuque	18,170	4,370	3,730	112·7
Grand'mere	24,600	2,000–2,600	3,314	78·3
Shawinigan Falls—				
No. 2	13,212	..	3,235	144·4
No. 3	14,071	4,000	3,538	144·4
La Gabelle	21,400	5,200–5,400	2,170	57·6

1·2. *Rapide Blanc.*—The Rapide Blanc pondage which is situated 100 miles below the Gouin dam is about 4 times as great as that at Grand'mere. The head available is 110 to 113 feet and the maximum flood recorded is 65,000 cusecs. Provision is made for possible flood of 150,000 cusecs, and the dam is constructed with the following :—

(1) Three sluice way 50 feet wide with sill 36 feet below head race level giving a capacity of approximately 43,000 cusecs each or a total capacity of approximat ely 129,000 cusecs.

(2) One sluice way 50 feet wide with sill 16 feet below head race level giving a capacity of approximately 12,000 cusecs.

(3) Two regulating gates for winter operation with a capacity of about 6,000 cusecs or total of 12,000 cusecs. These are of the pressure gate type with hoisting machinery, totally enclosed and intake below the lowest head race and therefore below the ice cap. The outlet is also kept constantly below water level by means of a weir built down stream.

The mean flow of the river here is 14,400 cusecs.

Dam.—The dam is of simple gravity type bulk head with no expansion joints.

The spacing between the units is 52 feet between turbine centre lines.

The intake opening top will be 27 feet below the head race level. This will avoid pond turbulence and suction in of trash.

Trash racks.—Each trash rack opening is 14 feet wide by 46 feet giving a total area of 1,288 square feet and a speed of 2·8 feet/sec. for the water. These are designed to withstand full hydrostatic pressure when totally clogged with debris. The unit stress is taken at 25,000 lb. per sq. inch. Six feet piers are located between each two openings leaving 18 feet between adjacent sets of intakes.

Rack grooves.—Rack grooves are at the extreme faces of the intake operated by a gantry crane.

Emergency Gates.—These gates using the same grooves as the trash racks are operated by the same gantry crane.

The gantry crane can also be used to lift up, if necessary, through openings in the gate house roof, any head gate for abnormal conditions or major inspection.

Vent Pipes.—Vent pipes are provided in case of a quick shut down of the turbine gates, thus preventing the creation of a vacuum in the penstock and the tendency to collapse. There are two or four vent pipes per intake unit. The upper part consists of a steel pipe and the lower part is formed into the concrete. These are each 18 inches diameter. The outlet opening of the vents are immediately on the down stream side of the head gate.

The plant is constructed of steel framed concrete.

The power plant building and the items of equipment which they house or accommodate, are as follows :—

Ninth Floor—Hoist.

Eighth Floor—(Area 7,000 square feet) 36 ton crane for intake, stop logs and head gates.

Seventh Floor— Regulating gate house.
Main gate house.
Elevator landing.

Fourth Floor —Battery for 250 V. D.C.
Battery for 48 V. D.C.
Operators' room.
Oil tank room—2–250 gallons reservoir tank for gravity oil feed to lubricate generator bearings.
2–60 gallons filter tanks and piping.

Superintendent's Office.

Third Floor—L.V. breaker room.
Telephone room.
Control room.
Outdoor Transformer bay.
Practice shop.

Second Floor—Field Office.
Electricians shop.
Conduit tunnel.
Transformer pipe tunnel.

First Floor.—Generator room.
O.C.B. relay room.
Oil filter and oil storage room.
4–5,000 gallons storage tanks for transformer oil.
1—200 gallons tank for circuit breaker oil.
3—Small electric pumps.
1—60 K.W. electrical heating tank for centrifugal machine for oil reclamation and oil filter press.

Generator pipe tunnel.

Pump pit—

2—2,500 gallons pump tank for the governor oil system.

2—890 gallons precipitation tank for the governor oil system.

1—250 lb./sq. inch air reservoir tank.

1—100 Do.

Penstock inspection tunnel.

Figure P.S. 1 gives an arieal view of the Rapide Blanc Power Station. Figure P.S 2. gives a close view of the Dam and Power Station, and figure P.S. 3 the Control Room.

Maximum output for Rapide Blanc Power Station.

Scope.—The data below gives a criterion of hydraulic operating efficiency applicable to Rapide Blanc Power Station. The purpose of this data is two fold—

(*a*) to indicate the maximum output possible under all conditions of discharge ;

(*b*) to provide a means of checking the station performance from the average daily discharge and to evaluate the factors which are responsible for the difference between the actual output and the maximum possible.

Losses in Hydraulic Operation.

In general the losses which occur in any hydro operation may be summarized as follows :—

(1) Loss due to operation at reduced head.

(2) Loss due to operating the station as a whole at an uneconomic discharge.

(3) Loss due to faulty load distribution among the units of the station.

(4) Leakage.

(1) *Loss due to operation at reduced head.*—This loss occurs whenever the station operates with the headrace elevation below the crest level. The maintenance of proper headrace conditions is primarily the function of the System Operating Department and the levels existing at any time follow a definite seasonal policy. For the purpose of this study the maximum possible headrace elevation is taken as 905·5 (905·50).

(2) *Loss due to operating the station as a whole at an uneconomic discharge.*—This item applies in the case where for regulation purposes the station is operated at a discharge which results in inefficient operation of the units. There are times when such operation is justified or unavoidable but under normal conditions there is no need to operate at any fixed load other than the most efficient. The question of proper load assignment is a responsibility of the System Operating Department but the station operators should not hesitate to point out gross errors which might result in poor loading conditions.

(3) *Loss due to faulty load distribution among the units of the station.*—Improper distribution of load among the units of a station may be due to careless operation or operation under conditions which make it difficult or impossible to maintain efficient load division. As an example of the foregoing might be cited the difficulty of keeping unit loadings balanced when the station is on frequency control. In this case spare generating capacity must be carried at all times to take care of load fluctuations and continued readjustment is required to ensure that the load is carried without undue loss. The carrying of excessive spare and unequal load division account for the greater part of this loss. The very worst condition

Figure PS 1—RAPIDE BLANC POWER STATION—AERIAL VIEW

Figure PS 2—Rapide Blanc Power Station—General view

Figure PS 3—Rapide Blanc Power Station—Control Room

is obtained by carrying all of the spare capacity on one unit, with several other units fully loaded. The loss due to faulty load distribution among the units is under the direct control of the station operators and is entirely their responsibility.

(4) *Leakage.*—The loss due to leakage is mentioned here only for the sake of completeness. It is difficult to evaluate and its prevention is entirely a matter of proper maintenance. No allowance has been made for leakage in this treatment.

Maximum possible output.—For a given expenditure of water maximum station output is obtained when—

(*a*) all units of the station operate at maximum efficiency ; and

(*b*) the headrace elevation is at the highest possible level.

Calculation of maximum possible output.—The maximum output obtainable for any discharge is given by—

$$KW = 0{\cdot}0848\ CQH.$$

Where C = maximum station efficiency.
Q = discharge, c.f.s.
H = maximum possible head.

The maximum possible head for any discharge is given by 905·5 minus the tailrace elevation corresponding to this discharge.

The maximum possible output for discharges from 1,000 to 20,000 c.f.s. at maximum head and best efficiency are given in the tabulation herewith.

Operating details which affect efficiency and output.—(1) A unit should never be operated at no-load. If required in reserve it should be kept on the bus as a condenser.

(2) The load or discharge assigned to the station should preferably be selected so that maximum efficiency is obtained. At 112 feet head the following are the best conditions :—

Station load.	*Station discharge.*	
KW.	C.F.S.	KW./C.F.S.
29,000	3,450	8·41
58,000	6,900	8·41
87,000	10,350	8·41
116,000	13,800	8·41

Any intermediate discharge is best obtained by operating part of the time at one of these loads and part of the time at another.

(3) For a given load assignment if there is any choice as regards the number of units to operate, the following consideration should apply :—

(*a*) It is more efficient to operate one unit wide open than to carry half of this load on each of two units.

(*b*) If the load exceeds the capacity of one unit wide open, two units equally loaded will run more efficiently than will either of the following combinations :—

(i) One unit wide open and the other carrying the balance of the load.

(ii) One unit at maximum efficiency and the other carrying the balance of the load.

From an inspection of the station efficiency curve the loading conditions for best economy at 112 feet head would be as follows :—

Station load.	*Station discharge.*	*Loading schedule.*
KW.	C.F.S.	
0	0	Motoring.
0 to 33,000 ..	0 to 4,090	Total load on one unit.
33,000 to 66,000 ..	4,090 to 8,180 ..	2 units equally loaded.
66,000 to 96,500 ..	8,180 to 15,680 ..	3 units equally loaded.
96,500 to 134,000 ..	15,680 to 17,000 ..	4 units equally loaded.
134,000 to 165,000.	17,000 to 20,000 ..	5 units equally loaded.

(4) On frequency control the units should be kept equally loaded as much as possible. Some loss will be unavoidable due to low loading but it can be kept at a minimum by frequent adjustment.

1.3. *La Tuque.*—The Latuque Power Station is served by a gravity type concrete dam 1,337 feet long. The dam consists in general of the west bulk head and corewall, the sluice section, the intake section and power-house and the east bulk head. There are five main sluices in the dam, two regulating sluices and a log sluice.

Provision is made for intakes for 6 turbines, each intake consisting of 2 water passages 15 feet wide connected to a 22 feet penstock. The penstocks are embedded in concrete. The intakes are closed by means of steel head gates with fixed rollers, the head gates being operated through line shafting by two motor reduction units. By means of Jaw clutches, either of the motor reduction units can raise any one of the head gates. The lowering and raising of the gates is actuated by push buttons in the gate house.

The 36-ton gantry crane on the top of the intake section is for lifting the gates out of their slots for painting and other maintenance works and also for handling the racks and emergency gates which are installed on the upstream face of the dam. Five units were installed at the time of the visit and there is provision for a sixth unit when required.

At 114 feet head each unit has a rated capacity of 44,500 horse-power at point of maximum efficiency and is capable of delivering 48,000 horse-power at full gate. Provision is made in the Power Station for heating the station in cold weather.

Figure P.S. 4 gives an aerial view of the Latuque Power Station and figure P.S. 5 its interior view.

1.4. *Trenche.*—Operating with a head of 160 feet, Trenche has an installed capacity of 325,000 horse-power with provision for an additional capacity of 65,000 horse-power.

The electrical layout of the Trenche Power House is indicated in Sketch P.S. 3. The units are normally operated on the unit system except that the breaker is omitted between the transformer and the bus and a 13·8 K.V. O.C.B. is introduced between the generator and transformer.

Figure PS 4—La Tuque Power Station—Aerial view

Figure PS 5—La Tuque Power Station—Interior View

Figure PS 8—TRENCHE POWER STATION—CONTROL ROOM

Figure PS 7—Trenche Power Station—Interior View

Figure PS 6—TRENCHE POWER STATION—GENERAL VIEW

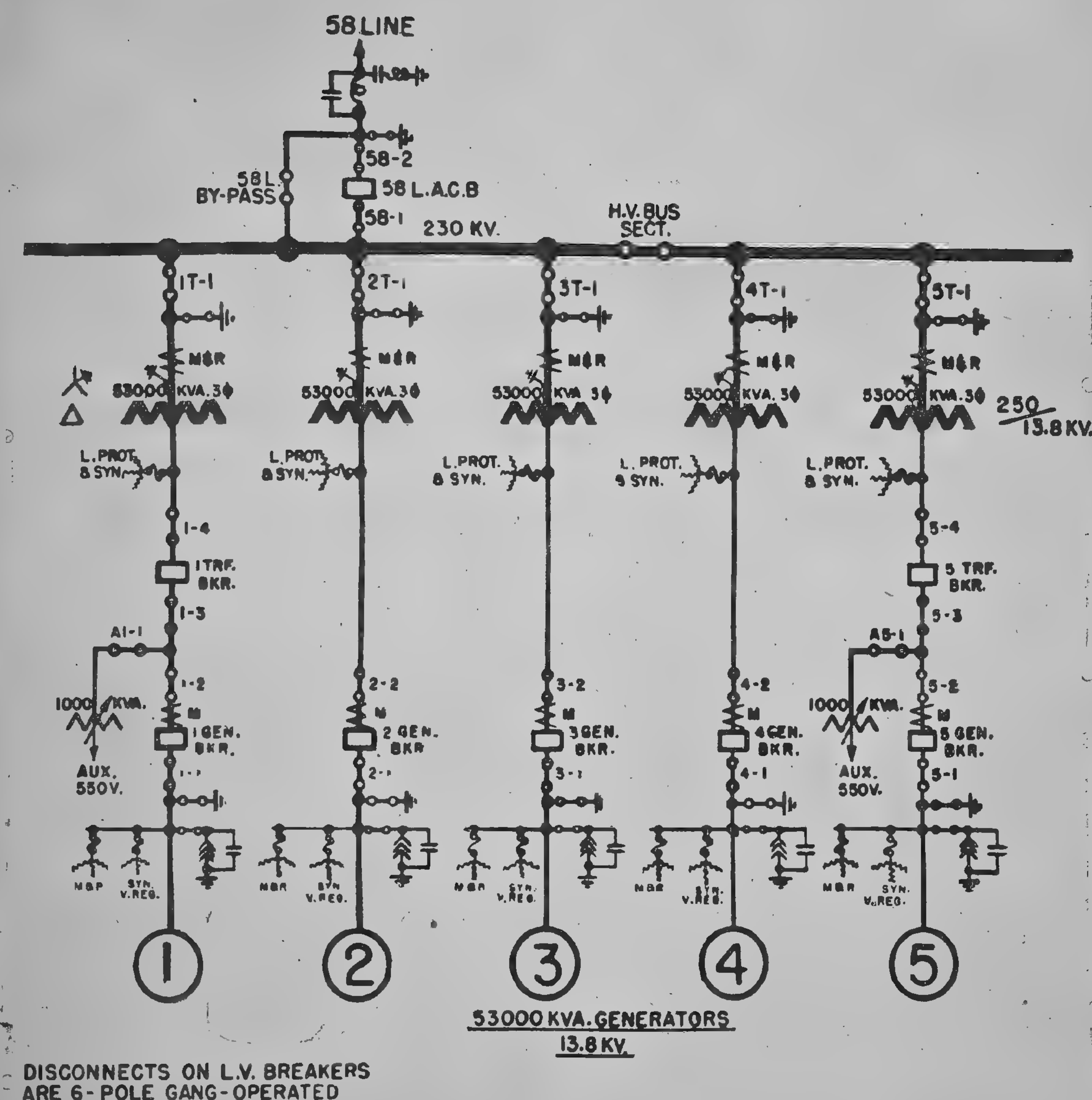
The generators 1 and 5 have unit transformers connected to the generators after the 13·8 KV. breakers for supplying the auxiliaries. The transformers are 1,000 KVA. 13·8 KV./575 V (△/△).

The power transformers are 53,000 KVA.)250 KV./13·8 KV) and star connected with the neutral earthed on high voltage side and delta connected on the low voltage side. They are outdoor and the type of cooling is OFW.

The 13·8 KV. breakers controlling the generators are air blast type made by the Westinghouse Company. The 230 KV. breaker controlling the line is also air blast of the Brown Boveri make, located outdoors.

Figure P.S. 6 gives an aerial view of the Dam and Power Station, Figure P.S. 7 an interior view showing the generators and Figure P.S. 8 the control room of the station.

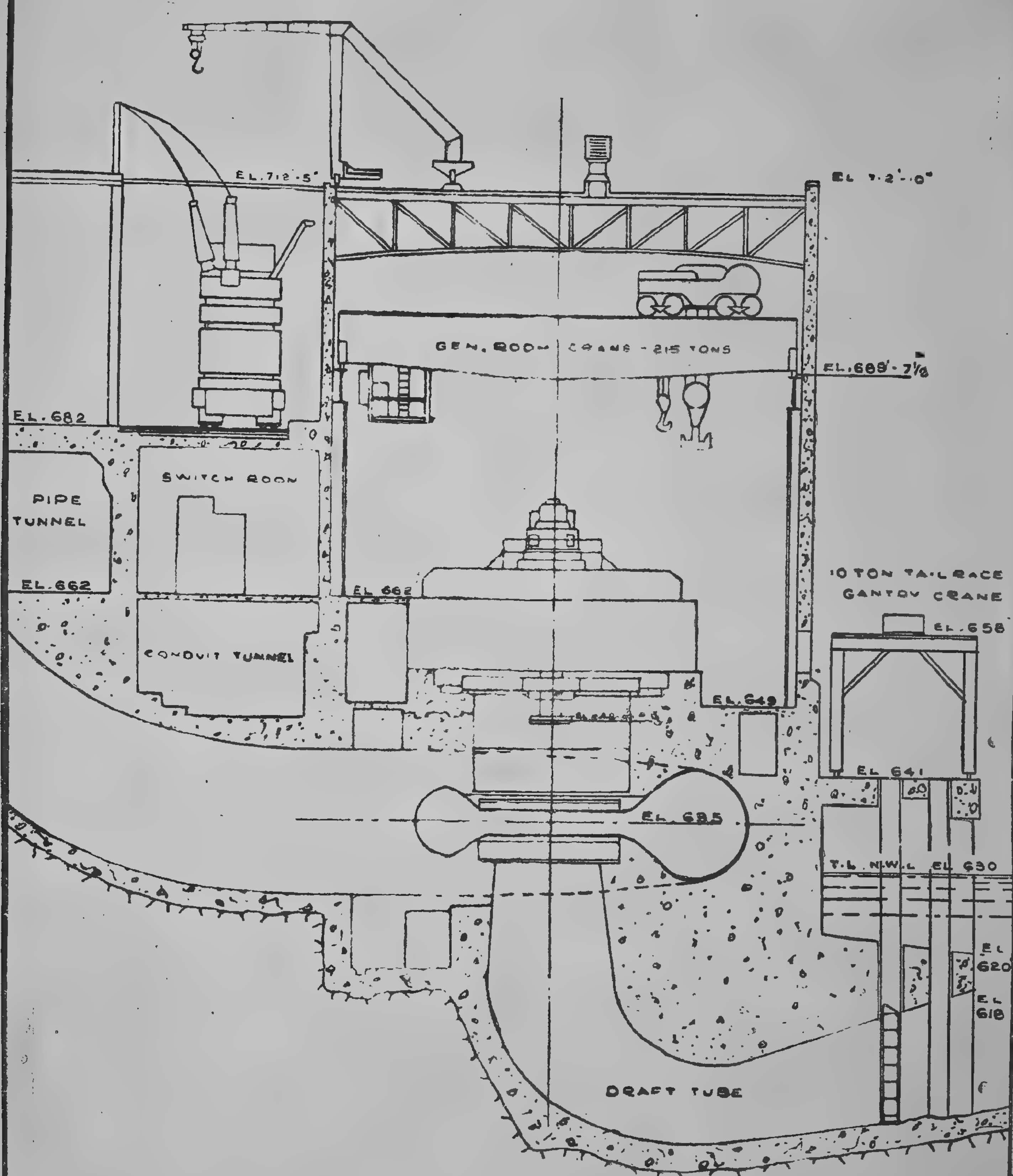
Typical cross section on centre line of a unit is given in Sketch P.S. 4.



ELECTRICAL LAY OUT OF TRENCHE P.H.

(SHAWINIGAN WATER & POWER Co.)

SKETCH PS. 3.



TRENCHE DEVELOPMENT, TYPICAL

CROSS SECTION ON ℄ OF UNIT.

SCALE: 1/16" = 1'-0"

SKETCH P.S.4.

1.5. *Grand'mere.*—Operating with a head of 80 feet, the station's present installed capacity is 200,500 h.p. with provision for an additional capacity of 25,000 h.p.

The power plant building and the items of equipment which they accommodate are as follows :—

Pump Room—
- 3—Transformer Cooling pumps.
- 3—Governor pressure water pump.
- 2—General service air compressors.
- 1—Air receiver tank.
- 3—Governor air compressors.
- 1—Air receiver tank.
- 4—Lubricating oil pumps.

L.V. Switch gallery—
- 34—6·6 K.V. breakers.
- 1,000 K.V.A. Transformer bank.
- 2—4,000 gal. tanks for transformer oil.
- 3—1,200 gal. storage tanks for lubricating oil.
- 2—1,200 gal. storage tanks for switch oil.
- 2—1,500 gal. gravity tank for switch oil.

Transformer Room—
- 3—6,600 V. O.C.Bs.
- 4—750 K.V.A. Transformers.
- 1—Grounding bank.
- 1—Auxiliary bank.
- 3—6·6/66 K.V.—30 M.V.A. banks.
- 1—6·6/110 K.V.—40,500 K.V.A. bank.
- 1—5,300 K.V.A. regulator bank for No. 4 bank.
- Relay room.

Battery Room—
- 2—300 H.P. M.G. sets.
- 1—Battery charging M.G. set.

H.T. Room—
- 13 K.V.—O.C.Bs.
- 300 gal. water tank.
- Air receiver.
- Automatic compressor.

Gate House—
- 1—450 K.V.A.—6,600/600 V Station auxiliary bank.

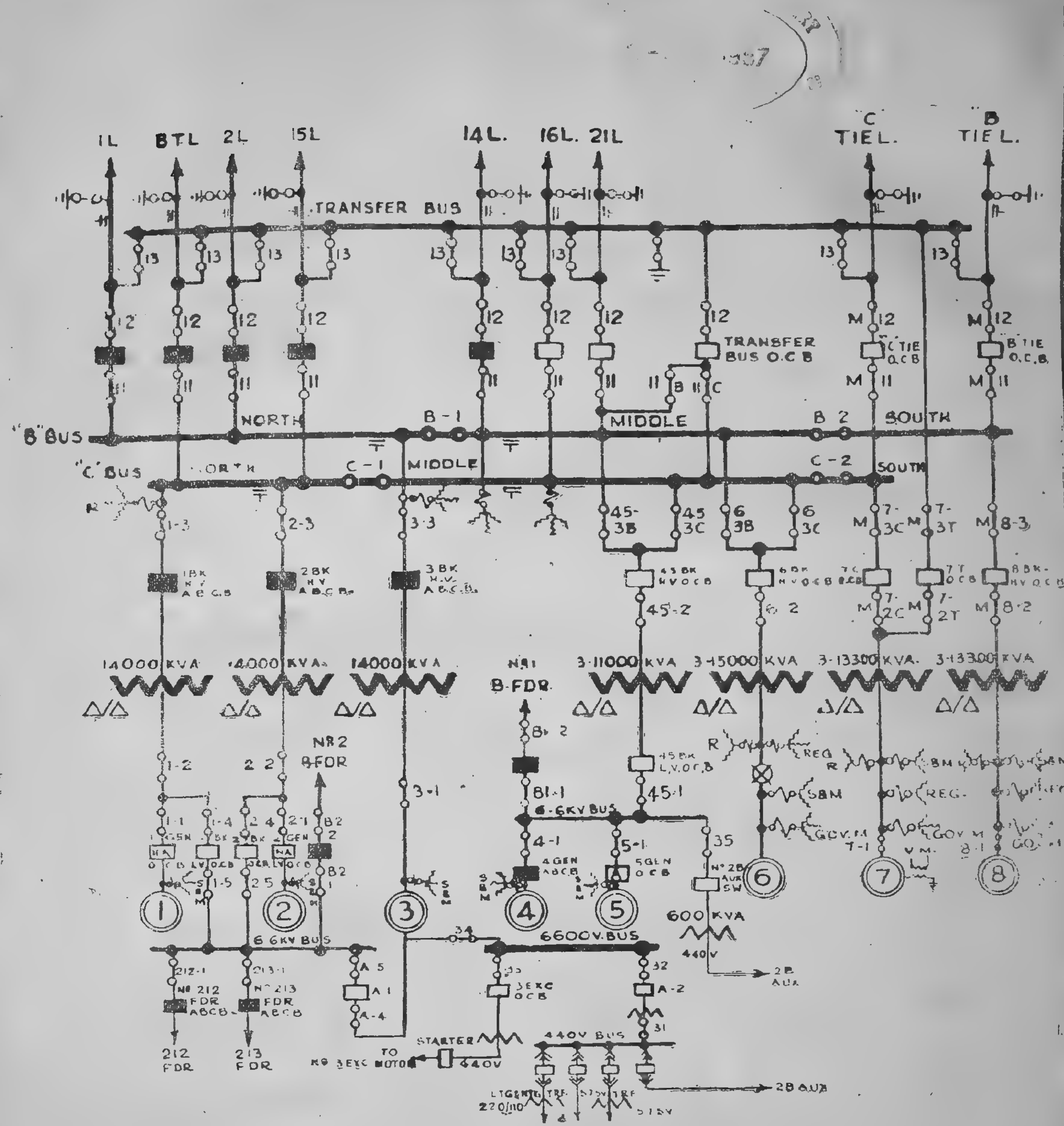
Generator Room—
- 8—18,500 K.V.A. and 1—25,000 K.V.A. generator.
- 4—Large transformer banks.
- 13—H.V. O.C.Bs.
- 96—L.V. O.C.Bs.

Figure P.S. 9 gives an aerial view of the Grand'mere Power station and Figure P.S. 10 an interior view showing the generators.

1.6. *Shawinigan Power-House No. 2.*—The Sketch P.S. 5 shows the switch diagram of No. 2 Power-House at Shawinigan Falls.

Figure PS 9—GRAND'MERE POWER STATION AERIAL VIEW

Figure PS 10—Grand'mere Power Station—Interior View



SWITCH DIAGRAM

No. 2 POWER HOUSE

SHAWINIGAN FALLS.

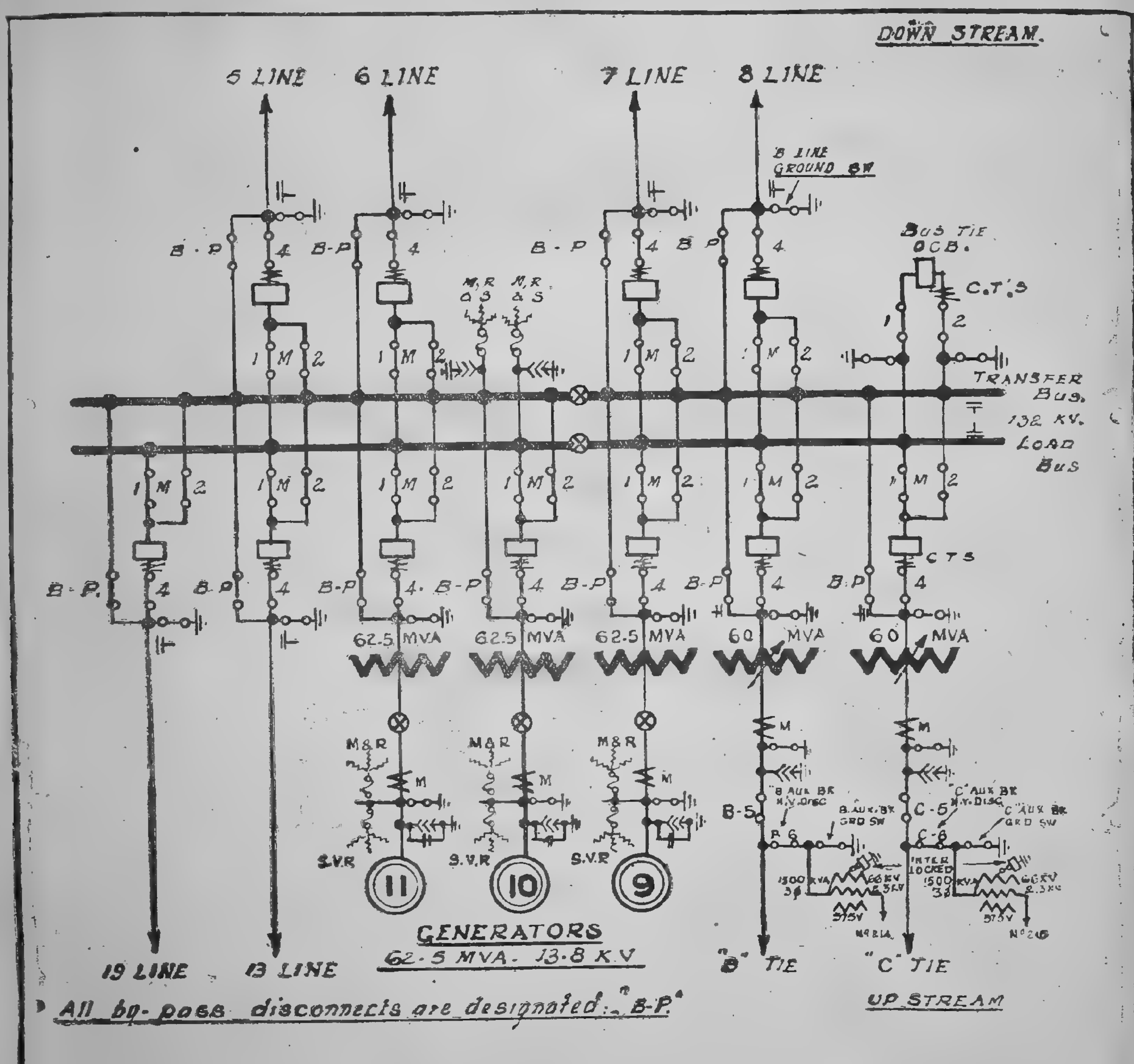
SKETCH. P.S.5.

1.7. *Shawinigan Power-House No.* 3.—The layout of the power-House is given in Sketch P.S. 6.

Photographs of Shawinigan Power Stations are given in Figures P.S. 11 to P.S. 15 as below :—

Figure P.S. 11—Aerial view of Shawinigan Power Stations Nos. 2 and 3.
Figure P.S. 12—Shawinigan No. 2 Turbine Room.
Figure P.S. 13—Shawinigan No. 2 Generator Room.
Figure P.S. 14—Shawinigan No. 3 Generator Room.
Figure P.S. 15—Shawinigan No. 3 Control Room.

1.8. *Lagabelle Power Station.*—Figures P.S. 16 and P.S. 17 give respectively the aerial view and interior view of the power station.



SWITCH DIAGRAM
No. 3 POWER HOUSE
SHAWINIGAN FALLS

SKETCH P.S. 6.

Figure PS 11—Shawinigan Falls Power Station Nos. 2 and 3—Aerial View

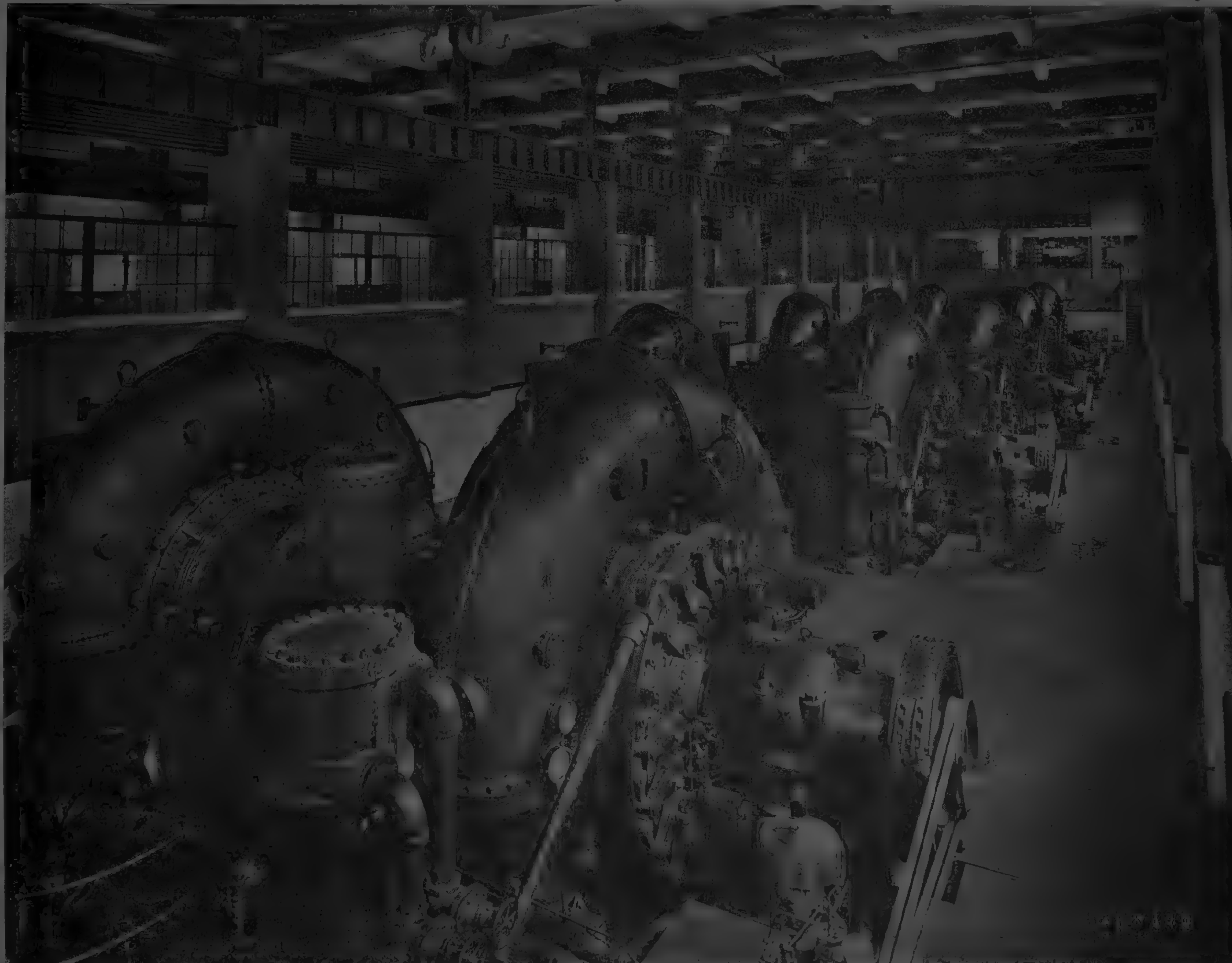


Figure PS 12—Shawinigan No. 2 Power Station—Turbine Room

Figure PS 13—SHAWINIGAN No. 2 POWER STATION—GENERATOR ROOM

Figure PS 14—SHAWINIGAN No. 3 POWER STATION—GENERATOR ROOM

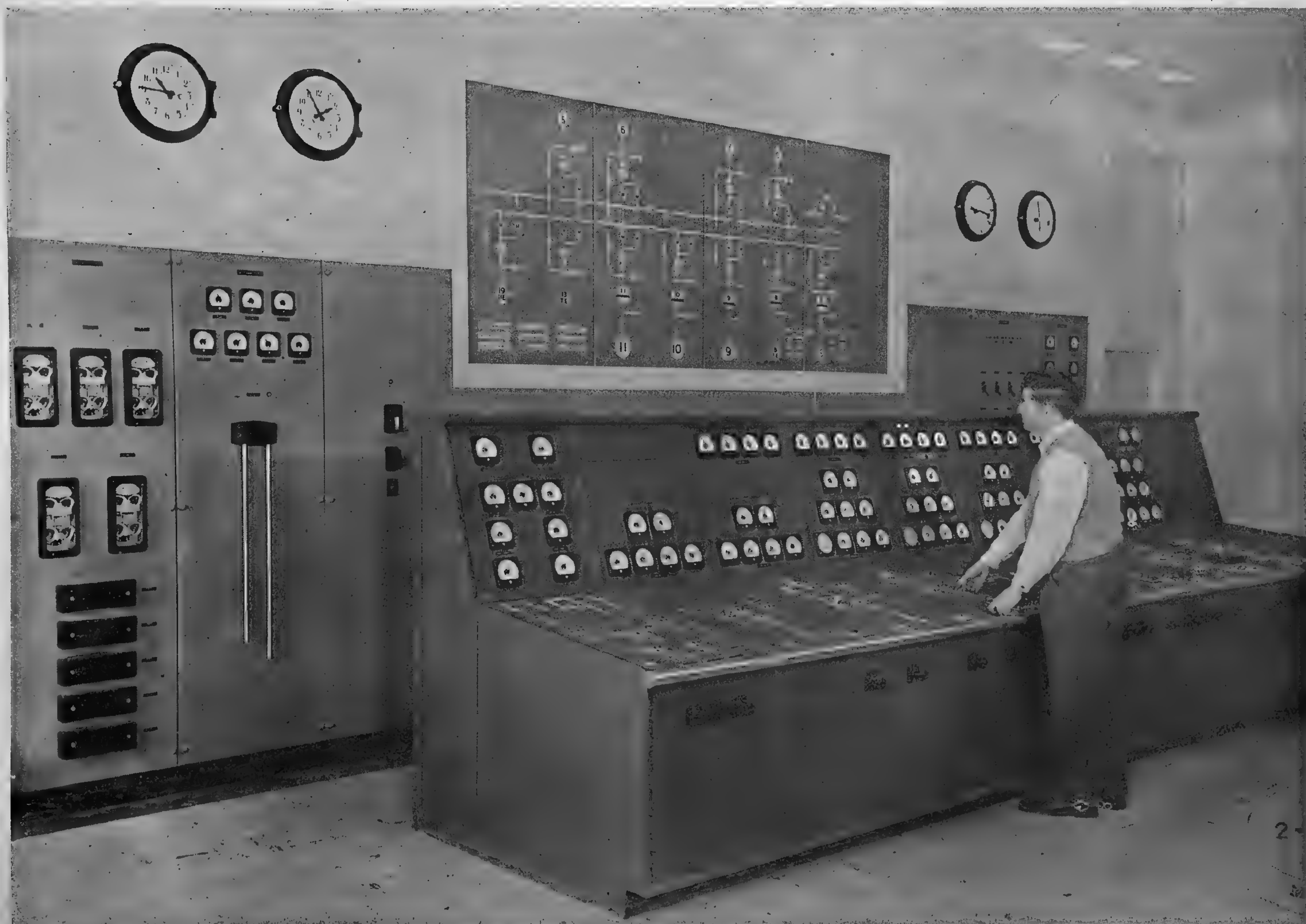


Figure FS 15—Shawinigan No. 3 Power Station—Control Room

Figure PS 16—La Gabelle Power Station—Aerial View

Figure PS 17—La Gabelle Power Station—Interior View

1.9. *Electric heating of rack bars in Hydro Electric Units.*—Frazil ice is formed in turbulent open water at zero temperature. The turbulence may be caused by conditions of stream flow or it may be due to high wind when ice begins to form on the water surface. It is in the shape of slender needle like crystals which if undisturbed spread over the surface and unite to form a continuous sheet. However, if the water is turbulent the needles are swept beneath the surface and distributed throughout the body of water to a depth depending upon turbulency. When these needles reach a set of rack bars at zero temperature, they are caught on the bars like so many fibres and a matted layer is formed at and near the surface of the water. This layer is more or less porous and will continue to build up until it is 6 inches or more in thickness. The needles freeze together and to the rack and form a mass which, while not nearly so strong as solid ice, it is practically impossible to clear off by mechanical means. At first the layer of ice forms on the bars only to the depth to which the needles have been carried by the turbulency of the water, but as the openings are stopped up near the surface, they are carried downwards by the entering water. Thus the layer is extended downwards until the flow is practically cut off. The head is apt to drop on the lower side of the racks due to the water draining away through the turbines and the resultant unbalanced pressure may be sufficient to crush the rack structure.

The best method of overcoming frazil ice troubles is through proper design of the hydraulic system above the rack bars.

A large body of quiet water will freeze over quickly and an ice covering of sufficient size will interrupt the frazil ice. This is due to the ice needle either adhering to the under side of the covering or being remelted in the warmer water under the ice.

If the velocity of approach is low and the racks are set at a considerable depth, and if in addition, the bed of the approach channel is smooth and grades down easily to the bottom of the racks, or even considerably below that, frazil ice troubles would be entirely eliminated.

The most common method of dealing with frazil is to raise the racks and let them pass through the turbine. Racks are usually made in two or more sections to reach them from top to bottom. It is usually sufficient to raise the top section from three to six feet. The upper rack will be covered with frazil but after that the needles are carried down and pass through the opening leaving the lower parts of the racks free of ice. Except in the case of very low heads the frazil passes through the turbine without giving any trouble. In some low head plants, electric heating has been applied to the runner, to keep it clear of ice. The worst objection to raising the racks is that it defeats the purpose for which the racks are intended (i.e.) to keep the trash out of the turbines.

Trash entering the turbines clogs up the water passages reducing the output of the unit, causes unbalance of the runner with consequent vibration and may do considerable damage to the runner and guide vanes. It is necessary to shut down the turbines frequently for cleaning during the time the racks are raised.

If it is desired to operate without raising the racks it is necessary to provide some form of heating for the rack bars in order to prevent the adherence of the frazil ice. At the Shawinigan Water Falls, electric heating has been adopted for this purpose.

In the design of this installation, use was made of the published data on the rack heating equipment in several Norwegian and Swedish plants.

The data available on the Norwegian and Swedish plants showed an energy consumption of from 140 to 425 watts per cusec. For the Shawinigan, provision is made to obtain an energy input of 225 watts per cusec with transformer taps provided to allow for a maximum of 425 watts per cusec if required.

The racks of the 40,000 KVA unit are arranged in five bays. Each bay is 12 feet wide and the racks extend to a depth of 25 feet 6 inches made up in three sections. The top section 10 feet 6 inches and the middle section 10 feet in length are heated. There are 48 bars of $3\frac{1}{2}'' \times 5/16''$ section in each bay. These are grouped 4 in parallel and twelve such groups in series. This gives a circuit length of 20 feet 6 inches $\times$ 30 feet or 615 sq. feet exclusive of connections. The two circuits obtained in this way are supplied with two phase 30 cycles current from the secondaries of two 750 KVA transformers connected to a 200 V circuit direct from the power house busbar.

Structural details.—The rack bars are supported by being electrically welded to pieces of structural steel angles. At top and bottom these angles are long enough to bridge eight bars and thus to serve to connect electrically one group of 4 bars to the next. The intermediate angles bridge 4 bars only. The angles are supported on oak pieces that are attached to rack frame and serve as insulation. The oak pieces are shaped, in order to support the weight of the bars in compression. Connection is made between the bars in the upper section and the middle section by means of fish plates, connection between the tansformers and the racks is made of two 5/16 inches $\times$ 5 inches copper bars in parallel laid in ducts and insulated by hardwood cleats.

Performance.—An average set of electrical readings on one transformer secondary and rack circuit is as follows :—

Voltage at transformer terminals—135.5 V.

Voltage at rack terminals—126.5 V.

Current—3,680 amps.

Output at transformer terminals—347 KW.

Loss in connections—7 KW.

Input into one rack circuit—340 KW.

Total input into racks—680 KW.

P.F. at the transformer terminals—69·7 per cent.

P.F. at the rack terminals—73·2 per cent.

Energy per C.F.S. of water—227 watts.

Sufficient experience has been gained with this installation. Several frazil ice conditions have been handled with entire success on several occasions. It has been found however that broken ice is cleared slowly by melting. If it comes into the racks in considerable quantities it is necessary to clear it off by hand in order to prevent the drop through the racks becoming excessive.

2. Quebec Hydro Commission.

2.1. *Beauharnois Power Development.*—One of the most important links in Canada's chain of hydro-electric developments is located on the south shore of the St. Lawrence river about 25 miles by road from Montreal, where the Beauharnois light, heat and power company utilizes the flow of the river to generate over 1,300,000 h.p. The ultimate capacity of the plant is expected to be 2,000,000 h.p. which is the second largest potential of any existing plant in the world, the largest being at Grand Coulee on the Columbia in the State of Washington.

The Beauharnois development located at the head of the Lake St. Louis, utilizes the 83 feet drop in head from Lake St. Francis and will ultimately use the whole flow of the St. Lawrence river, viz., 230,000 cusecs.

The steady flow of the St. Lawrence makes it unique among the large natural streams of the world supplied by the Lake Superior Water shed and stored in great lake systems. The water level does not vary from season to season and relatively few dams are required except those needed for control and for remedial works to maintain the existing water rights.

A canal 3,300 feet wide and about 15 miles long has been made as indicated in Sketch P.S. 7 to get the 80 feet head, and the power house spans the canal.

The 15 mile canal extends across the relatively flat country between the two lake and much of the canal area is below the level of the upper lake. Consequently, the canal is carried between dikes for its entire length. At the Lake St. Francis end, the dikes are low increasing gradually to a maximum height of 45 feet in the vicinity of the power-house forebay.

The layout of the Power Station and construction of the development is based upon step-by-step construction as needed to meet the power demand, thus keeping the initial cost at a minimum but allowing additional stages to be constructed economically without interfering in any way with the equipment already installed.

The first stage of the Power-house comprises an installation of 2 auxiliary vertical reaction generating units each of 8,000 h.p. and 14 main units of 53,000 h.p. each. These are open ventilated and are separately excited by means of A.C. motor driven M.G. units. A 13·2 KV ring bus fed from the two auxiliary units runs the whole length of the power house to feed the exciters and other station auxiliaries.

The forebay is common to the entire station but the tail race is in three sections with the spaces between the tail races utilized for the switching and substation structures necessary for handling the power.

At present, 65 per cent of the power requirements of the Montreal district are being supplied from this source and in addition large blocks of power are fed to the plants of St. Lawrence Alloys and the Aluminium Company of Canada which are located at Beauharnois close to the generating station. The province of Ontario is also being benefited to the extent of 300,000 h.p. of 25-cycle supply which is transmitted direct to Leaside substation in the Toronto area.

To meet the increased demand, the second stage of the power house to accommodate 12 units each of 55,000 h.p. was built as an extension of the first stage building. To keep the normal level of the water in the Lake St. Francis and St. Louis, two sluice way sections were also included. The Power-house is capable of extension for the maximum of 42 units of 50,000 h.p. each. The switching diagram of the station is given in Sketch P.S. 8.

BEAUHARNOIS DEVELOPMENT

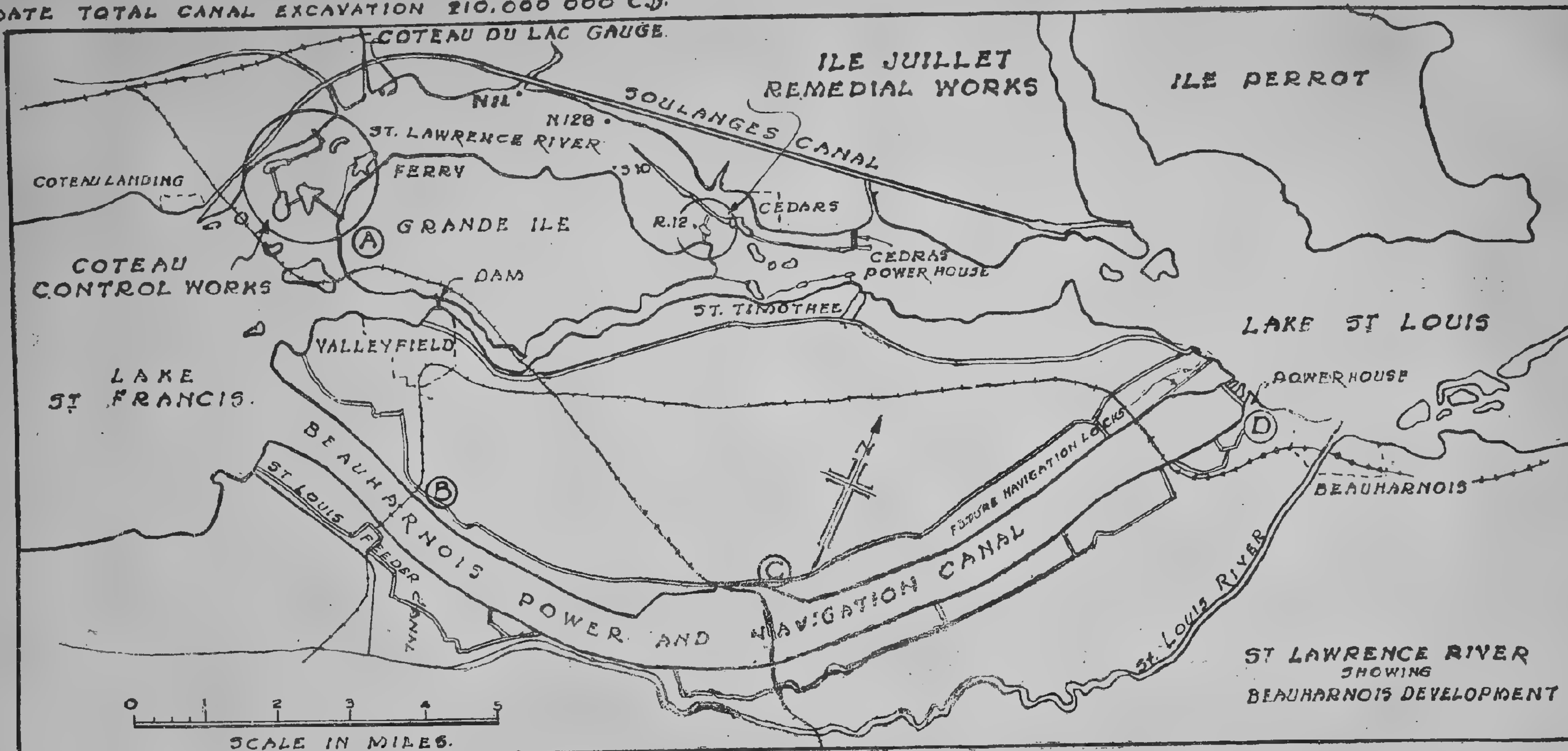
PRESENT INSTALLATION 20 OPERATING UNITS AND 6 UNDER CONSTRUCTION

PRESENT CAPACITY 1091000 H.P. ULTIMATE INSTALLATION: 36 UNITS WITH A TOTAL CAPACITY OF 2,000,000 H.P. (APROX)

LENGTH OF CANAL: 15 MILES. WIDTH OF CANAL: 3300 FT. OF WHICH 600 FT. ADJACENT TO THE NORTH EMBANKMENT FORMS A NAVIGATION CHANNEL HAVING A DEPTH OF 27 FT. AT LOW WATER.

VELOCITY OF WATER IN CANAL = 1·5 MILES PER HOUR. CANAL EXCAVATION TO DATE: 125,000,000 C.D.

ULTIMATE TOTAL CANAL EXCAVATION 210,000 000 C.D.



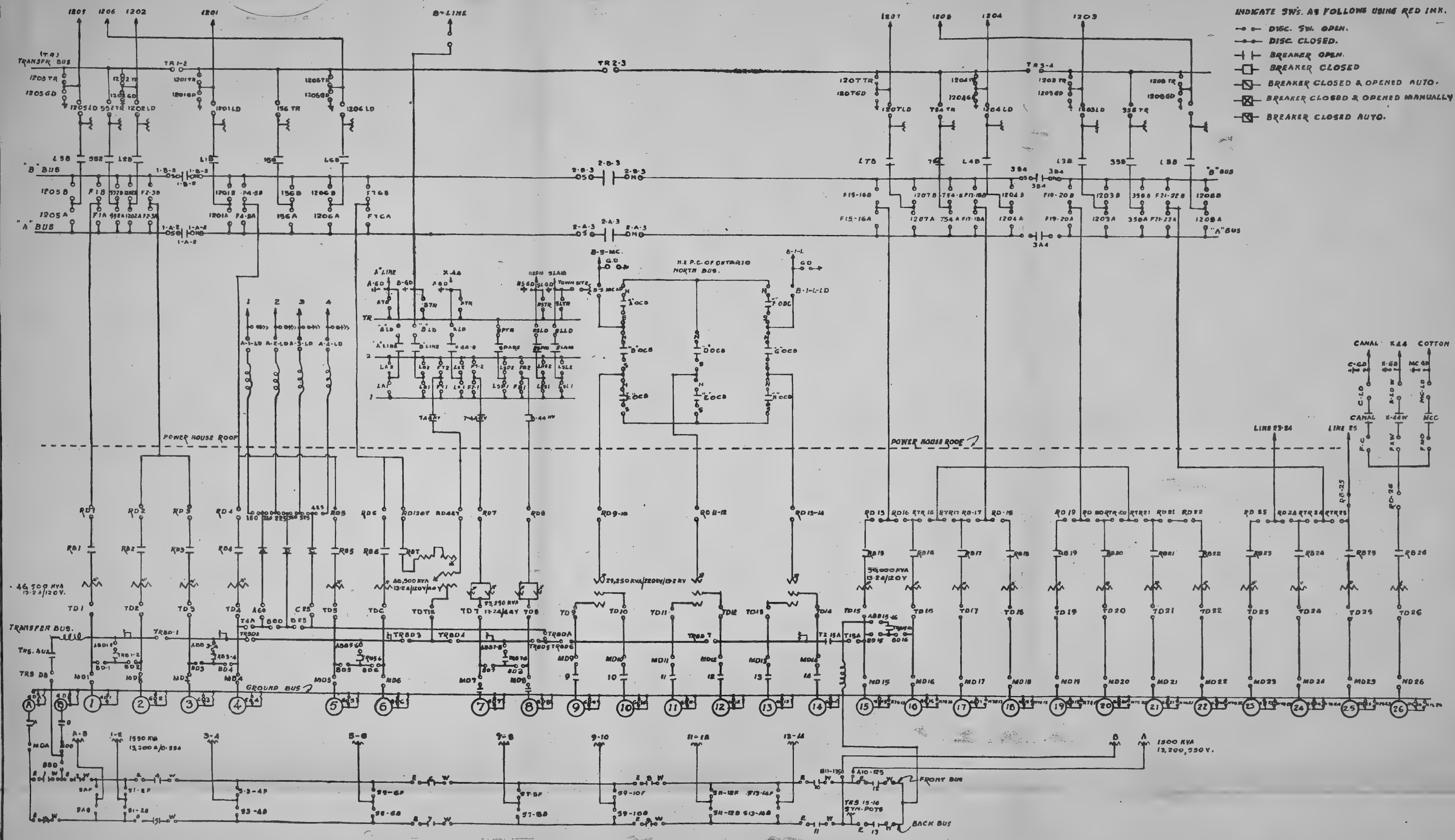
A – COTEAU CONTROL WORKS, COMPRISING ONE FIXED AND THREE MOVEABLE DAMS BY WHICH THE NATURAL LEVEL OF LAKE ST. FRANCIS IS MAINTAINED.

B – COMBINED HIGHWAY AND NEW YORK CENTRAL RAILWAY BRIDGE CROSSING OVER THE BEAUHARNOIS CANAL.

C – COMBINED HIGHWAY AND C.N.R. RAILWAY BRIDGE CROSSING OVER THE BEAUHARNOIS CANAL.

D – SITE OF THE BEAUHARNOIS POWER HOUSE.

SKETCH. P.8.7.



SWITCHING DIAGRAM
BEAUHARNOIS DEVELOPMENT

SKETCH. P.S.8.

2.2. *Location of plants and equipments.*—On the turbine floor is mounted the governor, governing equipment, water and oil supply pumps, oil filtration and storage system, space for repairing the mechanical and electrical equipment, machine shops and storage space. This oor is the main mechanical operating floor of the station, all control and indicating equipment for such operation being under the direct supervision of the turbine operators.

Between the generator piers and the downstream wall is a continuous gallery of sufficient width for a 10-ton truck to the entire length of the station, thus affording facilities for quick and convenient movement of small repair parts and other equipment.

On the generator floor is located the generators, motor-driven exciters, generator circuit-breakers, instrument transformers, etc.

In the annexure to the generator floor are mounted the individual control boards for each generator 550 V auxiliary cubicles.

Battery charging sets and battery are provided at the eastern end for the generating sets 1 to 14 and the other in the middle for the rest of the sets. Storage batteries have 2-motor generator sets for charging 250 V and 2 sets for 48 volts, while the new ones have rectifiers (Selenium).

The control house is laid out so that the maximum station installation of 2,000,000 h.p. can be cotrolled from this room.

2.3. *Station auxiliaries.*—A large capacity and reliable station service supply had been set up for the first stage with two station service water wheel generating units with an extensive 13.2 KV ring bus. A step-down transformer 1350 KVA 13,000/500 V is provided for the auxiliaries of each pair of units connectable to a differentially protected section in either the front or the back leg of the ring bus. The ring bus is extended to provide alternative feed for two 1,500 KVA transformers either of which could supply all the auxiliaries of the units of the second stage. These transformers are of the indoor dry type.

To add to the reliability of the station bus, an alternative connection is also provided to the L.T. transfer bus, so that the output of the 15th or 16th unit may be utilised for station service if required. Transformer switches are also provided so that in the event of failure of any ring section, the auxiliary transformers operating from the defective section, can be switched temporarily to the opposite ring section until normal ring closure is secured.

A duplicate 550 V bus, each of adequate capacity to supply all the auxiliaries is provided. At each of the cubicles, provided for distribution to the auxiliaries of a pair of units, duplicate switching and automatic transfer is provided so that in the event of failure of supply in one bus transfer to the remaining bus would be accomplished automatically. These busses are fed individually from the 2-1,500 KVA transformers for the second stage.

2.4. *Shipshaw Power Development.*—The Shipshaw Power Development is situated at tide water on the Saguenay river which in size and importance is the second among the tributaries of the St. Lawrence river. About 30,000 square miles of territory mostly virgin forest drain into the Lake St. John which covers an area of 400 square miles. From this natural reservoir the Saguenay river rushes 30 miles through rocky gorges with a total drop of 320 feet to tide water and then falls into the St. Lawrence. There is another generating station at Isle Maligne near lake St. John which utilizes a head of 110-feet and the development at Shipshaw utilizes the balance of 210 feet of head close to the tide water at the mouth of the Shipshaw river.

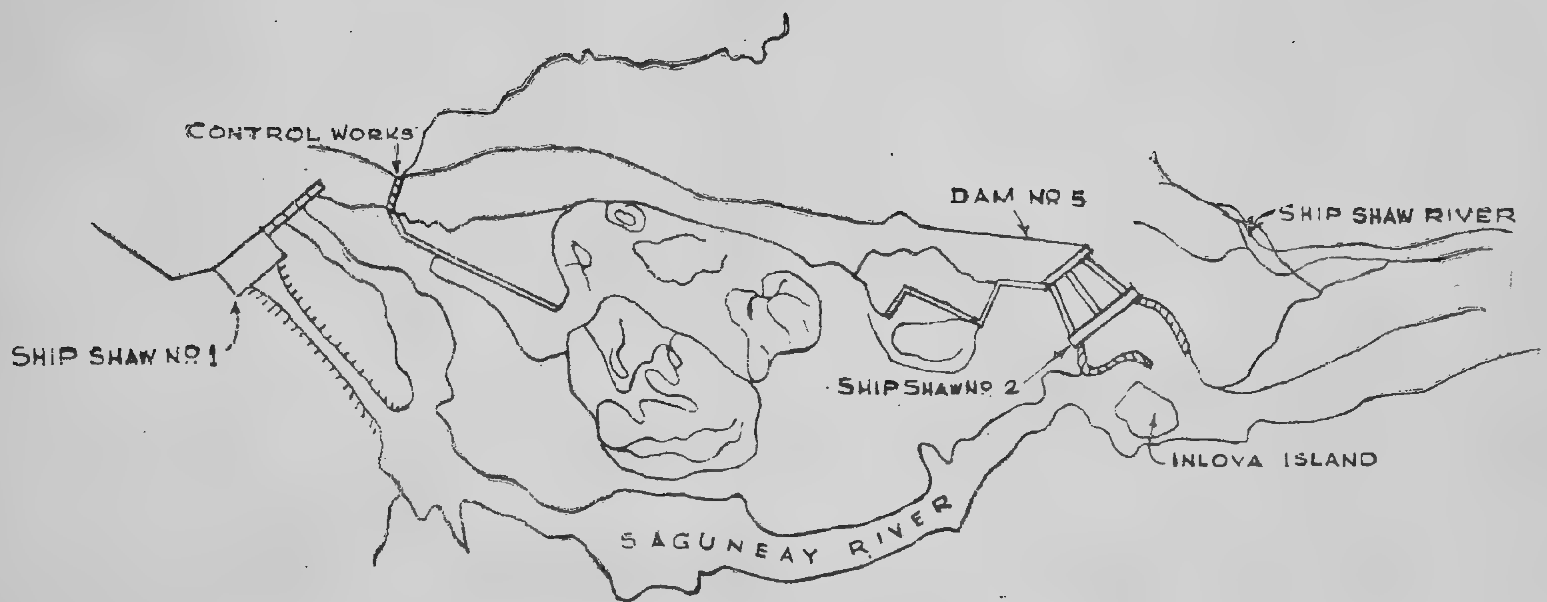
The Shipshaw Power Station supplies power to the world's largest aluminium smelter. Both the power house and the aluminium smelter are within the City limits. The Shipshaw scheme is intended to pass all the ultimate volume of the regulated flow of the Saguenay river through the Shipshaw wheels. Whenever sufficient wheel capacity becomes available in the Shipshaw plant No. 2 all the water will be passed through Shipshaw plant No. 2 the No. 1 station being by-passed so far as the production of power is concerned.

Water conditions—

	Cusecs.
The maximum recorded flow in the St. John	400,000.
The maximum recorded flow at Saguenay River	325,000.
Average flow of Saguenay River	52,000.
Average regulated flow of the Saguenay River	46,000.
Firm regulated flow of the Saguenay River	42,500.

Diagrams showing the Shipshaw development are given in Sketches P.S. 9, P.S. 10 and P.S. 11.

The total installed capacity of Shipshaw No. 1 Power-house is 300,000 KVA. (4 units of 75,000 KVA each) while that of No. 2 Power-house is 1,200,000 KVA (12 units of 100,000 KVA). The Power-house has 2 Nos. 185 tons cranes which can be coupled to lift the heaviest individual piece weighing 390 tons.

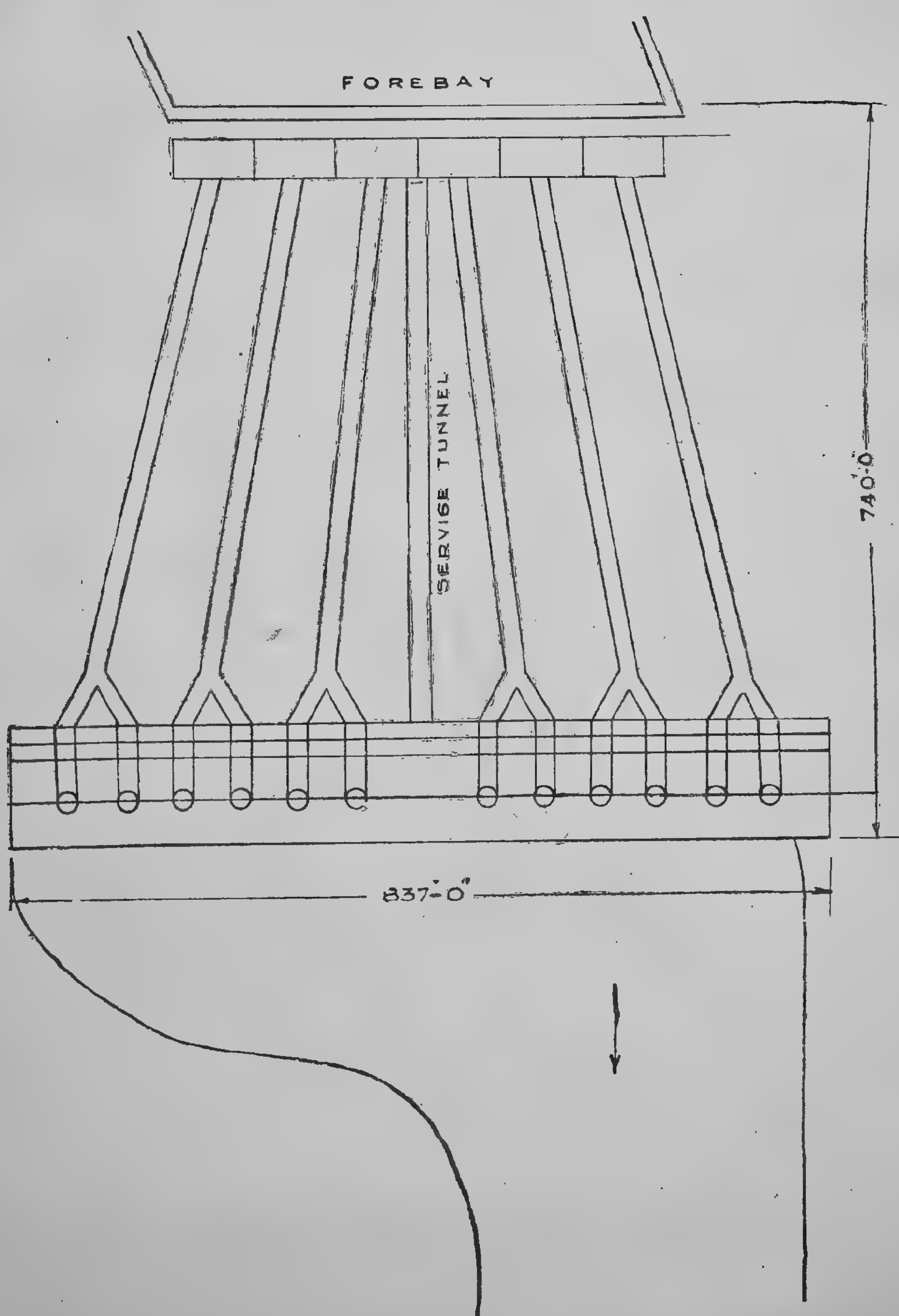


SHIPSHAW Nº 2 - DEVELOPMENT

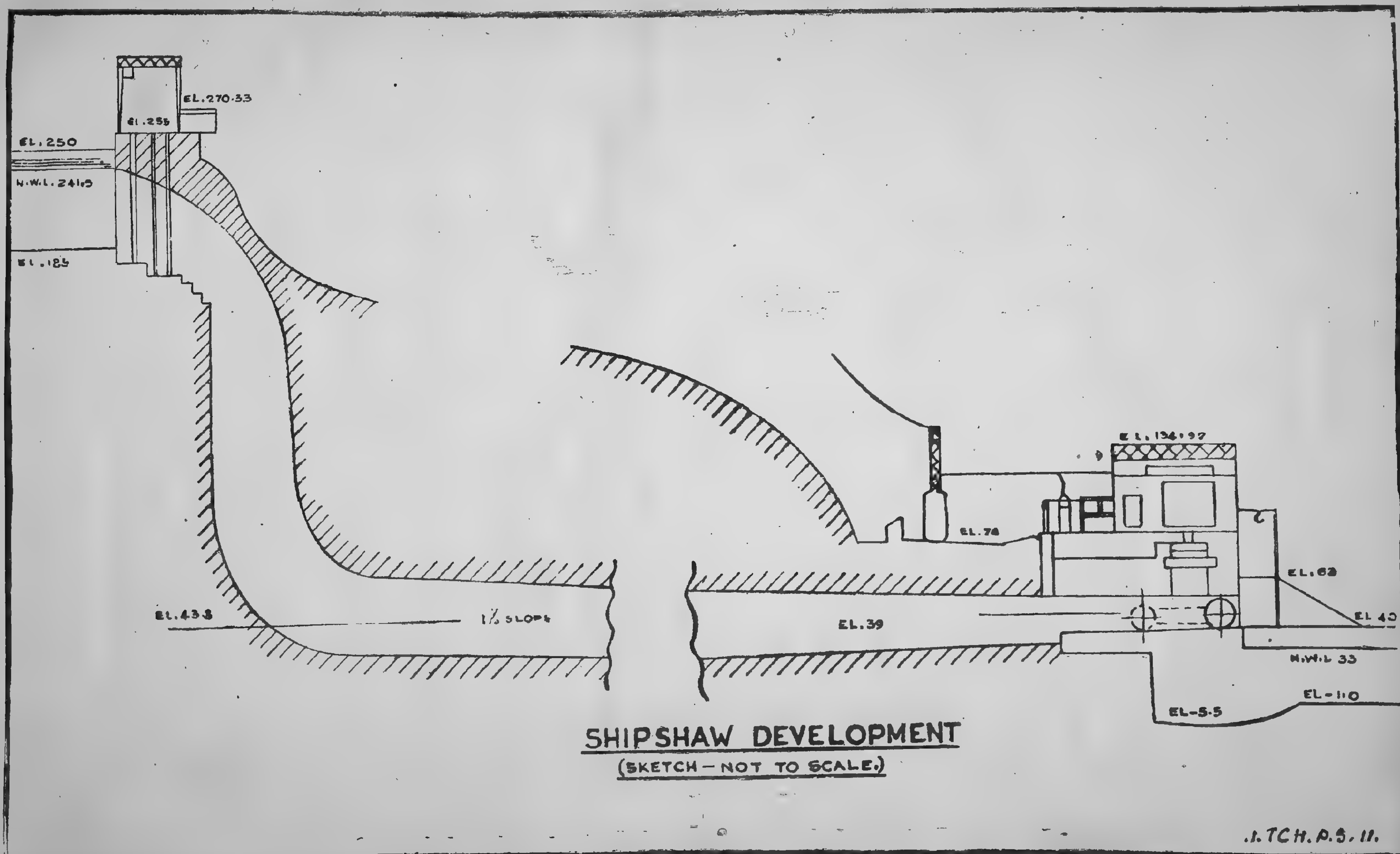
SKETCH P.S. 9.

SHIPSHAW DEVELOPMENT

(NOT TO SCALE)



SKETCH. P.S.10.


EL.270.33
EL.255
EL.250
N.W.L.241.5
EL.185
EL.43.8
1% SLOPE
EL.39
EL.78
EL.134.97
EL.63
EL 40
N.W.L 33
EL-1.0
EL-5.5
SHIPSHAW DEVELOPMENT
(SKETCH—NOT TO SCALE.)
J.TCH.P.S.11.

SKETCH P. S. 11.

Statistical Data of Shipshaw Development.

Dams—

No. 1 dam—

Length—3,000 feet.

Height above lowest bedrock—192 feet.

11 Spillways, each 45 feet wide × 33 feet deep.

Dams 2, 3a, 3b, 4 and 5 have a total length of 5,855 feet.

Canal—

Length—$1\frac{1}{2}$ miles.

Width (minimum)—300 feet.

Depth (minimum)—33 feet.

Tunnels—

6—Concrete lined, each 30 feet diameter and 800 feet long.

Shipshaw No. 1 Power house—

Head of water—160 feet.

Installed turbine capacity— 300,000 h.p.

Shipshaw No. 2 Power house—

Head of water—210 feet.

Installed turbine capacity—1,200,000 h.p.

Total usable storage capacity—400 billion cubic feet.

Station service.—Two service busses that could be tied together if necessary by means of air circuit breaker are provided. Each is supplied by a 1,500 KVA 3 phase 13·2 KV/600 V pyranol filled transformer and controlled by a 15 KV 600 amperes 3-pole oil immersed electrically operated disconnecting switch (indoor) connected to each of two generators.

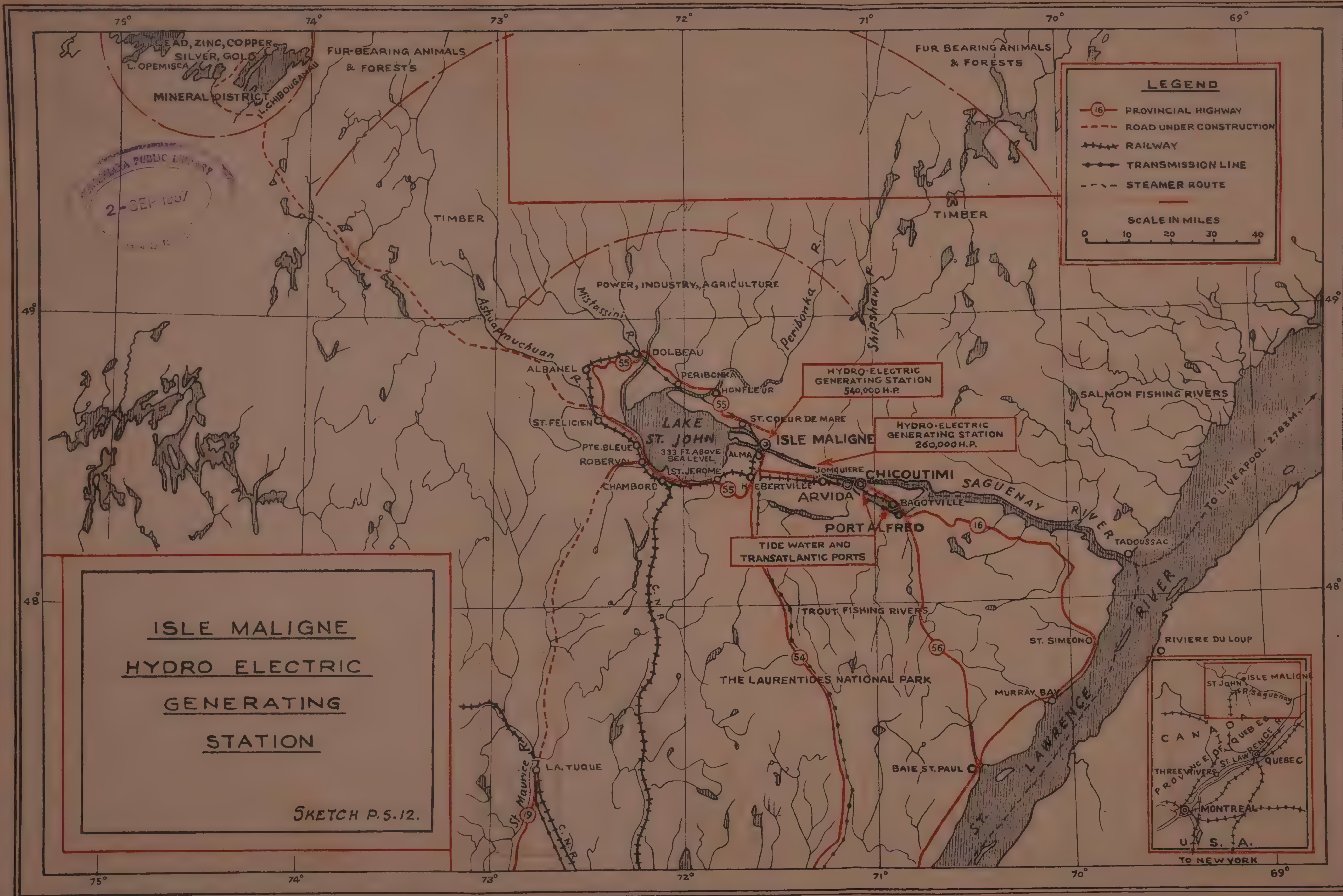
The oil immersed disconnects are interlocked so that only one generator can be connected to each transformer at a time as the generators are on the unit system, one generator, one transformer and one line, right up to Arvida receiving station.

Under normal conditions, one generator 5 or 6 will be connected to that service transformer and supply one half of the main service bus and one generator either 7 or 8 will be connected through the other service transformer and supply the other half of the service bus and the tie breakers between these busses will be kept open. In the case of a fault that would cause loss of energy in one transformer, the circuit breaker controlling this transformer will open out automatically and the bus breaker could be manually closed restoring full power-house service.

All service feeders are so arranged that they can be taken off the service bus sections alternatively. The service bus and auxiliary feeders are contained in sheet steel cubicle type board.

The control room is located in the central section, rear of the generator room.

The power house is 837 feet long. For this reason, it was obvious that all auxiliary services, oil, water, air, electricity, etc., should be as nearer as possible to the transverse centre line of the power house building.



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A control section at the centre of the transverse power-house centre line, containing the control board, control wiring, relays, sumps, pumps, compressor, batteries, transformers, switch, oil, transformer oil filter equipment, service boards, office, etc., is provided and the main units are spaced right and left in groups of 6.

Similarly, all gravity water drainage is outletted with a main pump installed in the basement of the control section.

2.5. *Isle Maligne Power-house.*—This power-house is a typical design in which the power-house and water intakes are made part of the dam or impounding structure located as far down the stream as possible so as to obtain the maximum possible head for development.

The power house is located at Isle Maligne immediately below the outlet of the Lake St. John (vide sketch P.S. 12). The plant operates under a normal head of approximately 110 feet and has a total installed capacity of 540,000 h.p.

The Lake St. John serves as a forebay for the plant. This has a storage capacity of 200 billion cubic feet. The water is drawn into the intake at an average depth of 30 feet below the surface, the top of the intake always being submerged. The rack structures forming the upstream portion of the power-house bulk head is built of R.C.C. and structural steel. There are four steel rack sections 39 feet high and 9 feet 3 inches wide per opening.

The installed generating capacity of this station is 420,000 KVA. (12 units of 35,000 KVA. each).

Normally, each generator feeds its own transmission line and operates on the unit system.

The interesting features of the Isle Maligne Hydro-Electric Development are as follows :—

Reservoir—

Area of water shed—30,000 square miles.

Area of lake St. John—400 square miles.

Volume of storage in lake—200 billion cubic feet.

Dams—

On Grand Discharge—One earth dam and four concrete dams.

On Little Discharge—Three concrete dams.

Regulating gates—23 gates of 17·5 feet × 40 feet.

11 gates of 27·5 feet × 40 feet.

Flow—

Maximum recorded flow of the river—325,000 cusecs.

Average recorded flow of the river—52,700 cusecs.

Maximum discharge of water wheels—46,000 cusecs.

Generating station—

Length of power house—720 feet.

Width of power-house—163 feet.

Intake—Twelve 22-foot dia. penstocks each with two 16 feet by 22 feet butterfly valves.

Average head of water—110 feet.

Number of units—12 numbers.

Water wheels—Francis reaction turbine vertical type 128 inches diameter, 45,000 h.p. 112·5 r.p.m.

Diameter of waterwheel shaft—29 inches.

Generators—Rated 35,000 KVA. 13·2 KV 60 cycles with direct connected to 210 KW. 250-V exciters.

Weights—

Complete generator and exciter—396 tons.

Generator rotating parts—175 tons.

Complete water wheel—550 tons.

Water wheel rotating parts—89 tons.

Number of power transformers in station—22 numbers.

Transmission voltage—13·2, 26·4, 66, 110, 154 and 187 kilovolts.

2.6. *St. Lawrence River Project.*—This project extends to the United States as well and the following are the installed capacities :—

Canada (36 units)—1,100,000 h.p.

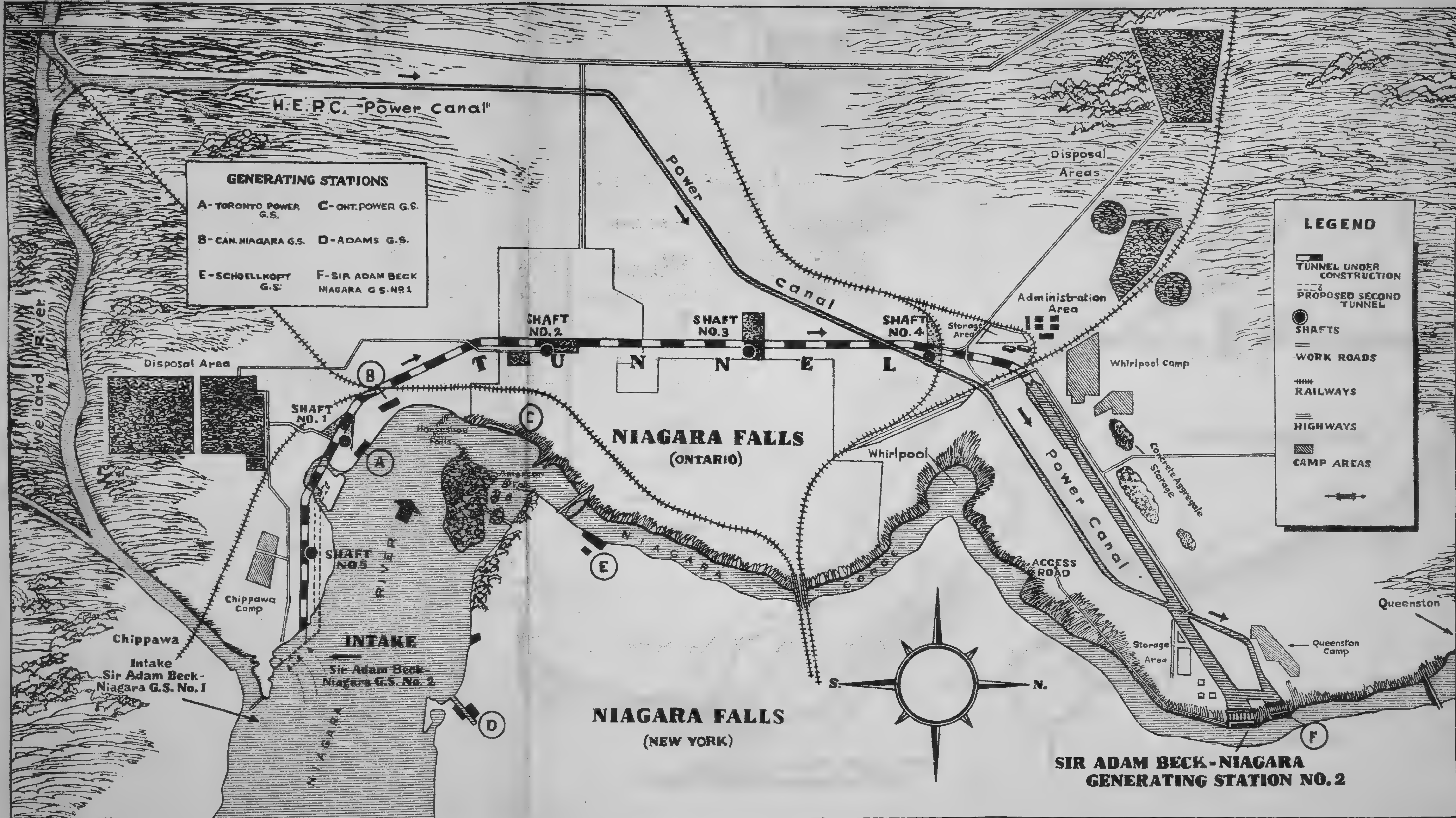
U.S.A.—940,000 KW.

3. Hydro-Electric Power Commission of Ontario.

3.1. *The Niagara Power Development.*—The Niagara River joining lake Erie to lake Ontario has a fall of about 326 feet in its course of about 35 miles. For the first 20 miles from the lake Erie to the upper rapids, the Niagara is a broad stream varying from half to one mile width and the fall of the river in its 20 mile run is only about ten feet. The drop in the upper rapids is about 55 feet in a stretch of one mile.

The Canadian side of the falls is 162 feet high and crest length of 2,600 feet with a depth of water of about 12 feet at the centre. The American side of the falls is 167 feet high and 1,000 feet wide with an average depth of one and half feet.

The average discharge of the river is 210,000 cusecs and the water shed area is about 260,000 square miles. Lake Superior, Heron, Michigan, Erie, the four largest lakes, are above the Niagara River and act as balancing reservoirs for the run off.



NIAGARA GENERATING STATIONS.

SKETCH P.S. 13.

The development of power from the waters of the Niagara River is regulated by a treaty between Canada and the United States of America and with a view to preserve the scenic beauty of the falls, it was decided that water for the falls should be regulated as follows and the balance only utilized for power development :—

The minimum flow necessary over the falls—

November 1st—March 31st (winter)—50,000 cusecs.

April 1st to September 15th—100,000 cusecs from 8–22 hours, 50,000 cusecs for the rest of the day.

September 16th—October 31st—100,000 cusecs from 8–20 hours, 50,000 cusecs for the rest of the day.

This treaty will allow Canada and the United States of America to use greater amounts of water for power generation, most of the time, particularly during winter when power demands are high.

Power is supplied to the Niagara Power System from three generating stations—Queenston, Ontario and Toronto Power Stations (vide sketch P.S. 13). A new generating station Sir Adam Beck, No. II, is now under construction adjacent to the Queenston Power-house on the upstream side and this is expected to go into service by 1954.

3.2. *Queenston (Niagara No.* 1) *Power-house.*—The general scheme of development comprises an intake structure on the Niagara River at Chippawa, the deepening and enlarging of the Welland River, with a reversal of its flow for four miles, the construction of a canal eight and three-fourth miles long from Montrose on the Welland River to the forebay and screen house which are situated on the cliff above the power-house on the Lower Niagara River, where the banks rise 300 feet above water level, about one mile south of the village of Queenston.

The waters of the Niagara River are diverted above the falls and rapids by a special intake structure built in the Niagara River at the mouth of the Welland River at Chippawa. The intake structure consists of six large tunnels 32 feet square at the intake end and are submerged about 10 feet below the water surface. They are assembled in a structure 830 feet long across the entrance to the Welland River and at an angle down stream from the Niagara River shore line. This angle in the structure allows the ice flow to slip off into the main river stream above the submerged intake tubes.

The water thus diverted passes along the deepened and enlarged channels of the Welland River for a distance of four miles. It then enters the Canal proper and traverses the Niagara peninsula for a distance of eight and three-fourth miles, passing through an earth section and then into the rock cut section of the canal through a control gate (an electrically operated roller sluice gate of 48 feet clear span). The canal is 48 feet wide and is lined with concrete throughout the rock section of the canal. The capacity of the canal is 14,000 cusecs. The depth of the water varies from 35–40 feet and at one point, the flow of the canal is more than 140 feet below ground level. The canal terminates in a forebay which is a triangular shaped enlargement of the canal and is situated near Queenston at the edge of the Niagara River.

Along the edge of the Niagara gorge 320 feet above the river surface is built the screen house. This is 550 feet long and has 32 openings on bays three for each of the ten main units and one is for the penstock supplying the two auxiliary turbine generator units and the other opening is for the ice chute. The three openings converge to a penstock 16 feet in diameter and 383 feet long.

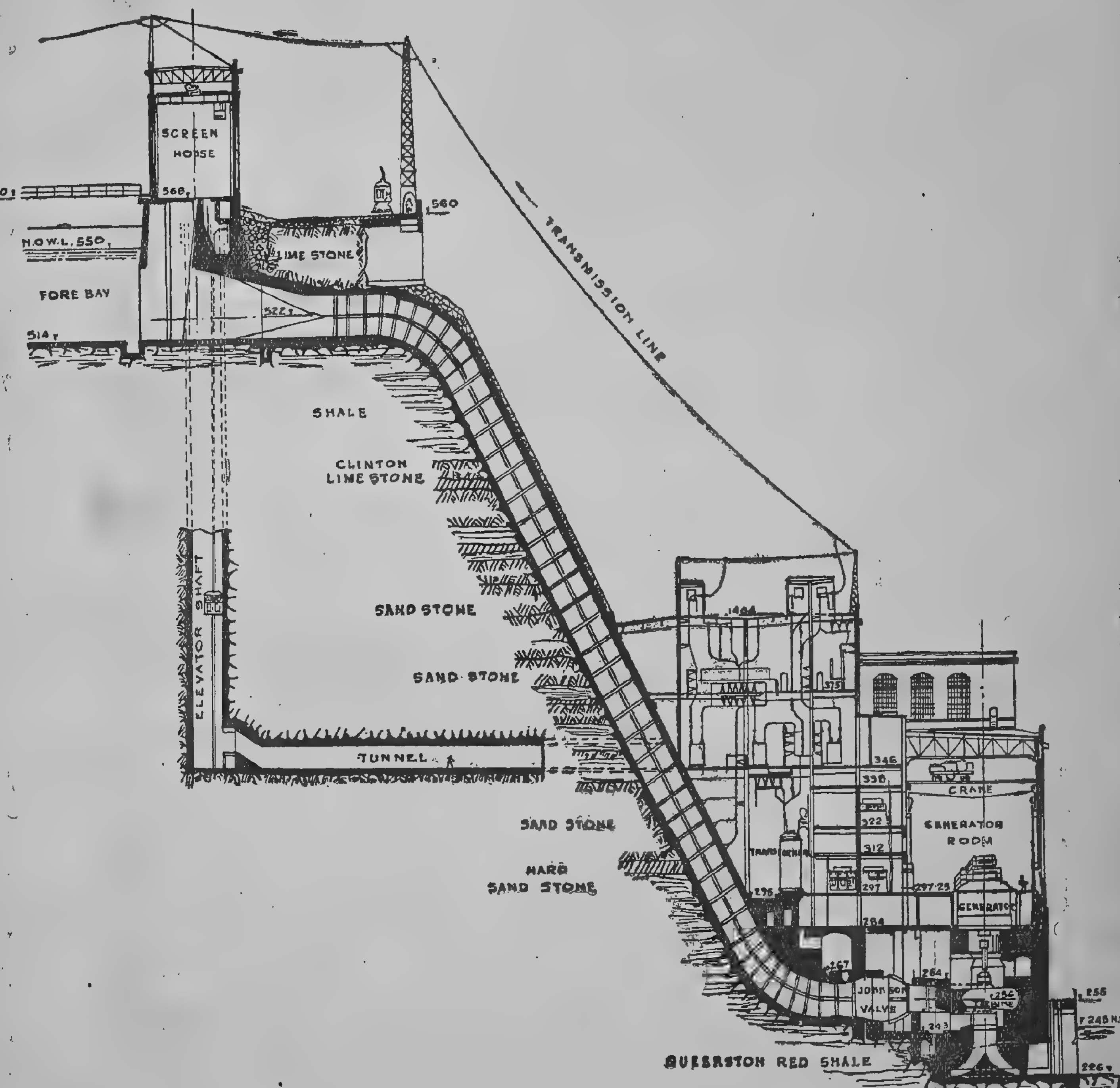
Water passes into the penstocks through 5-inch mesh screens on trash racks. The screens are usually removed in winter because of the ice which enters the canal mostly from the Welland and some from the Niagara River.

When there is ice in the forebay some is let over the ice chute gate and a greater portion is digested by the turbine. Three steel gates set one upon another to a height of 54 feet are required to shut the water off one opening and nine such gates are required to shut the water off all three openings to one main unit penstock.

From the headworks water is conveyed through ten steel penstocks each 16 feet diameter at the upper end and 14 feet at the lower end and one 5 feet diameter penstock for supplying the two auxiliary turbines all laid in trenches excavated in the gorge face and leading to the generating station in the gorge below (vide Sketch P.S. 14). A 14-foot large plunger type Johnson valve is installed at the lower end of each penstock and is arranged to close automatically in the event of an emergency, viz., the scroll case burst, etc. The valves can be operated by remote control from the control house.

The head gates are motor operated (individual) and can be dropped from the control house in the event of an emergency.

The power house is situated on the edge of the river at the bottom of the gorge. It is about 560 feet long and 180 feet high containing ten units of capacities 55,000 to 65,000 horse power each operating under a head of 294 feet at 187·5 r.p.m. The turbines are of the vertical single runner Francis reaction type direct coupled to its generator. The units are air cooled. The generation is at 12 KV 25 cycles.



QUEENSTON
GENERATING STATION
NIGARA RIVER.

SKETCH P.S. 14.

Automatic synchronising and control at Queenston Power-house.—The units in all the three plants are equipped with automatic synchronizers and automatic facilities for starting and stopping a unit by push button control. Pushing the start button operates a solenoid on the pilot valve of the governor to open the turbine gates and the governor controlling the speed. When the unit is within 5 per cent of the normal speed, the automatic synchronizer takes control adjusting frequency, voltage and phase angle of the unit to match those of the system, then closes the circuit after which the operator assumes control to adjust load and voltage. Taking a unit out of service after adjusting load to zero is accomplished by pushing the stop button. This operates the governor solenoid, closing the gates. After the speed drops to about 50 per cent the brakes are automatically applied to bring the unit to rest.

3.3. *Niagara No. 2—Sir Adam Beck No. 2 Generating Station.*—This station which will eventually have 12 units each of 105,000 h.p. is located about 6 miles below the fall on the side of the precipitous 300 feet cliff of the lower Niagara River gorge and just upstream of the Niagara Power-house No. 1.

Water diverted from the upper Niagara River through two intake structures will be conveyed beneath the city of the Niagara falls by huge twin circular tunnels of diameter 51 feet each $5\frac{1}{2}$ miles long, with a capacity of 20,000 cusecs each. They will be lined with 3 feet thick concrete reducing the diameter to 45 feet. The tunnels run parallel at a distance of 250 feet centre to centre. The tunnels will follow a stratum of limestone averaging 10 feet in thickness and providing an adequate protective cover. The depth will vary from about 330 feet near the intake to about 220 feet just before the angle of emergence is reached.

The shafts used on the tunnel were offset in such a manner that they could also be used for the construction of the second tunnel.

The intake for each tunnel will consist of a 500 feet long concrete gathering tube located along and parallel to the present shore line, to take advantage of the main current of the river. They will be completely submerged.

Re-emerging the surface on the other side of the City the tunnels will empty into a $2\frac{1}{4}$-mile canal which will carry the water to the forebay of the station.

The canal will have an average width of 200 feet and an average depth of 70 feet and has a capacity of 40,000 cusecs. The canal will be inclined through rock with the exception of a stretch of 2,200 feet. In this part which is the site of an ancient gorge which was filled with glacial debris, a trapezoidal concrete trough will be built to carry the water.

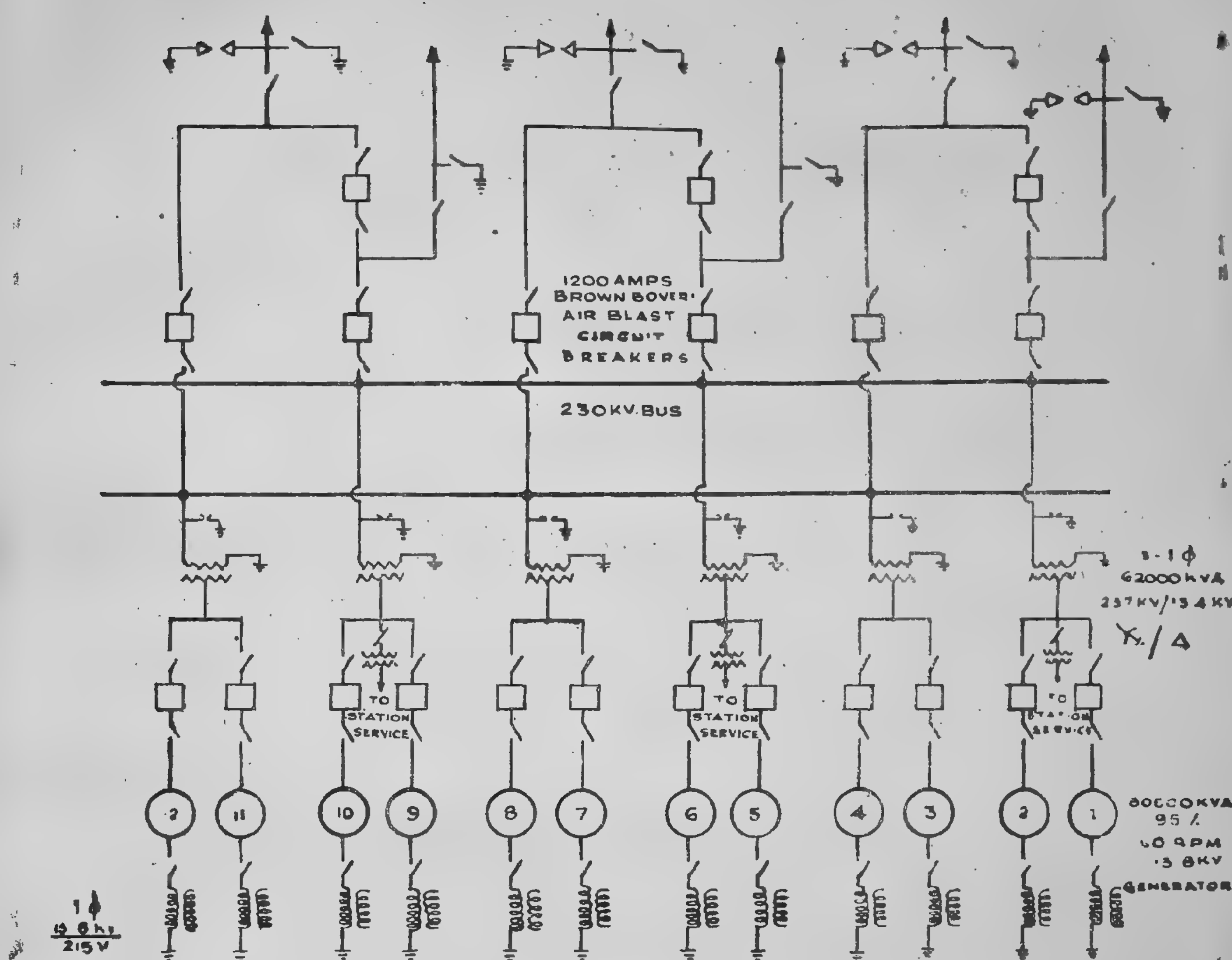
Near the forebay, the canal crosses the canal of the Power-house No. 1 in a unique crossing. The flow in the two canals is redistributed at this intersection. The redistribution of flow is arranged by an interconnecting canal between the forebay of 1 and 2 Power-house.

The Power-house is 931 feet long 63 feet wide and 50 feet high. The turbines are of the reaction type made by the Dominion Engineering Company. The turbines are 105,000 horse power capacity each with a speed of 150 r.p.m. operating at a head of 294 feet.

The generators are of capacity 80,500 KVA each (0·95 P.F.) and the voltage at which power is generated is 13·8 KV. They will have main and pilot exciters (6 G.E. and 6 of the Westinghouse make).

The transformers will be outdoor.

The Sketch P.S. 15 shows the electrical layout of this station.



ONTARIO H.E.P.C.

SIR ADAMBECK GENERATING STATION

SKETCH. P.S 15.

Load and frequency control at Niagara No. 2.—Automatic load control is provided for the 80,500 KVA units all operating in parallel with the Southern Ontario 60-cycle system.

(i) *Remote master controller.*—The plant will be controlled most frequently by a Leeds and Northrup master load frequency controller located at the Power Supervisor's Office, Toronto, from which raising or lowering impulses will be transmitted to the plant over the communication lines. This master controller may operate on either flat frequency control, flat tie line control or tie line bias control for the regulation of the Southern Ontario 60-cycle system.

(ii) *Local flat frequency controller.*—Necessary equipment is included for maintaining the load of any unit at a predetermined average value and for shifting its load or speed setting at a predetermined adjustable rate from any existing value to any other predetermined value. This control will be usable on one or more units, independently and concurrently, with the action of other types of control on one or more other units.

(iii) *Forebay level control.*—Provision is made for the control of the plant load by a forebay level controller. This controller is for purposes of adjusting the total plant load to maintain a constant forebay level and to provide for automatic shifting of the forebay level to any predetermined new level at a predetermined rate. Forebay level control will not be used concurrently with frequency or tie line control.

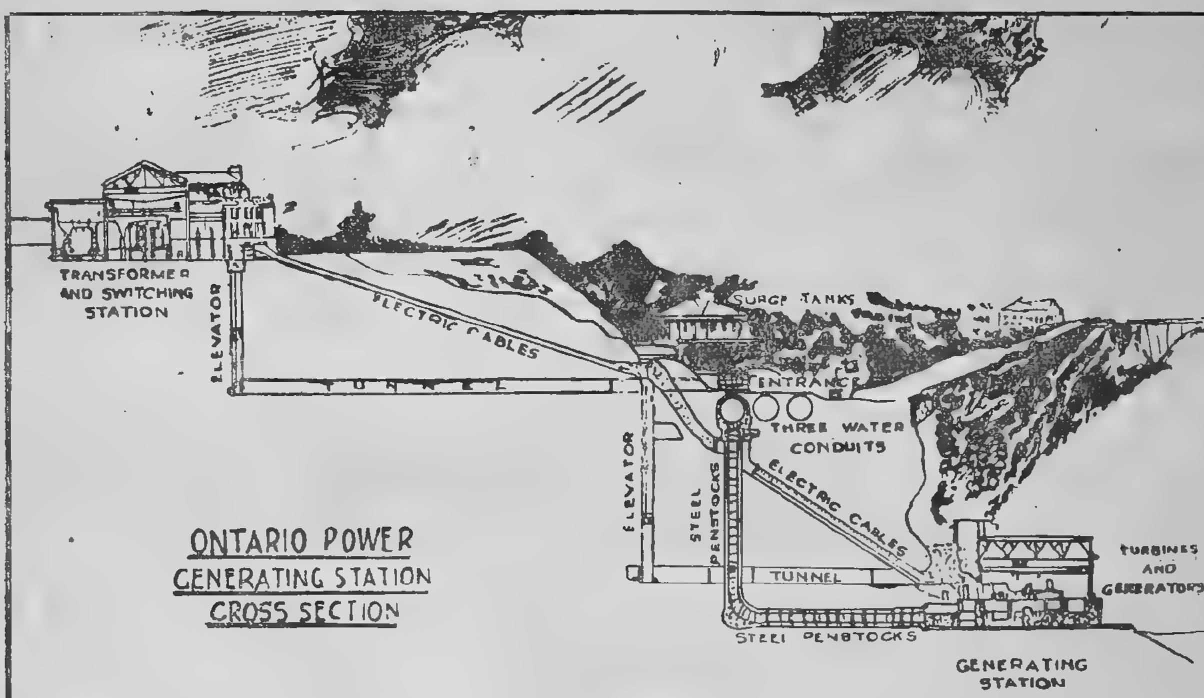
(iv) *Automatic load dividers.*—Equipment is included for automatically dividing the load changes among any two or more units which are being controlled concurrently from the same regulating source. Means are provided for adjusting the load division so that there may be a predetermined difference in unit loads relative to one another. The load dividers are of a type which allows control impulses to go to only one unit at a time so that the response in megawatts per impulse of given duration may be kept uniform.

(v) The automatic control is to work through the medium of the turbine governors which are Woodward twin cabinet actuators and is to be applied through the governor synchronising motors.

(vi) A measurement of the total generated Power (KW) is to be telemetered to the Regional Operator's Office, Niagara Falls, and thence to the Power Supervisor's Office, Toronto, where it may be used as a basis for automatic load division between this new plant and other plants on control at the same time in order to spread the load regulating duty and minimize load surges on anyone plant.

3·4. *Ontario Power Station.*—This generating plant formerly owned by the Ontario Power Company of the Niagara Falls, installed in 1910, was purchased by the Commission on behalf of the municipalities and enlarged to a capacity of 180,000 horse-power. It is situated below the cliff near the foot of the Horseshoe Falls and opposite the Goat Island. It operates under a head of approximately 180 feet. The water is taken from the river about a mile above the crest of the Canadian Falls and is conveyed to a distance of 6,500 feet through two large conduits each 18 feet in diameter, one of steel with a concrete envelope and the other of R.C.C. and a third wood stave conduit 13 feet 6 inches diameter. All these conduits terminate in a surge tank (each having its own surge tank).

At the portals of these conduits, are provided three electrically operated head gates. Just beneath the top of the cliff behind the Power house, there is a long underground chamber called the valve chamber, the roof of which supports the above conduits. Water is conveyed through steel penstocks, 225 to 317 feet in length—14 of 9 feet in diameter and 2 of 10 feet 6 inches placed in tunnels passing through solid rock to the generating station (vide Sketch PS 16). The valves one for each penstock and can be operated from the control room.



SKETCH P.S. 16.

The Power-house contains 16 turbines of double runner horizontal central discharge type with a speed of 187·5 r.p.m. and ranging in capacity from 11,700 to 20,000 h.p. connected directly to their respective generating units. The total installed capacity is 180,000 h.p. and power is generated at 12 KV, 25 cycles. The power generated is transmitted through cables to the transformer station at the top of the cliff where it is stepped up to 110 KV and 60 KV.

Each generator has its individual M.G. set for excitation. The motors are supplied from 2 turbo-generator sets 1,600 h.p. served by a 4 feet diameter penstock, from No. 2 conduit. The generators are of capacity 900 KW and power is generated at 3-phase 25-cycles and the voltage of generation is 2,200 V. A 600 h.p. motor is also attached to each 900 KW generating unit for operating the D.C. excitation system for 10 minutes in the event of a fault on the auxiliary turbines.

There are also 2-M.G. sets (DC) each capable of carrying the entire exciter load of the Power-house.

The turbines are provided with relief valves operated by the governor. The governors are pressure oil operated and belt driven from the turbine.

The neutrals of the generators are insulated while those of the 110 KV step-up transformers, the windings are star connected with the neutrals of 2 units joined together, are grounded through a water rheostat.

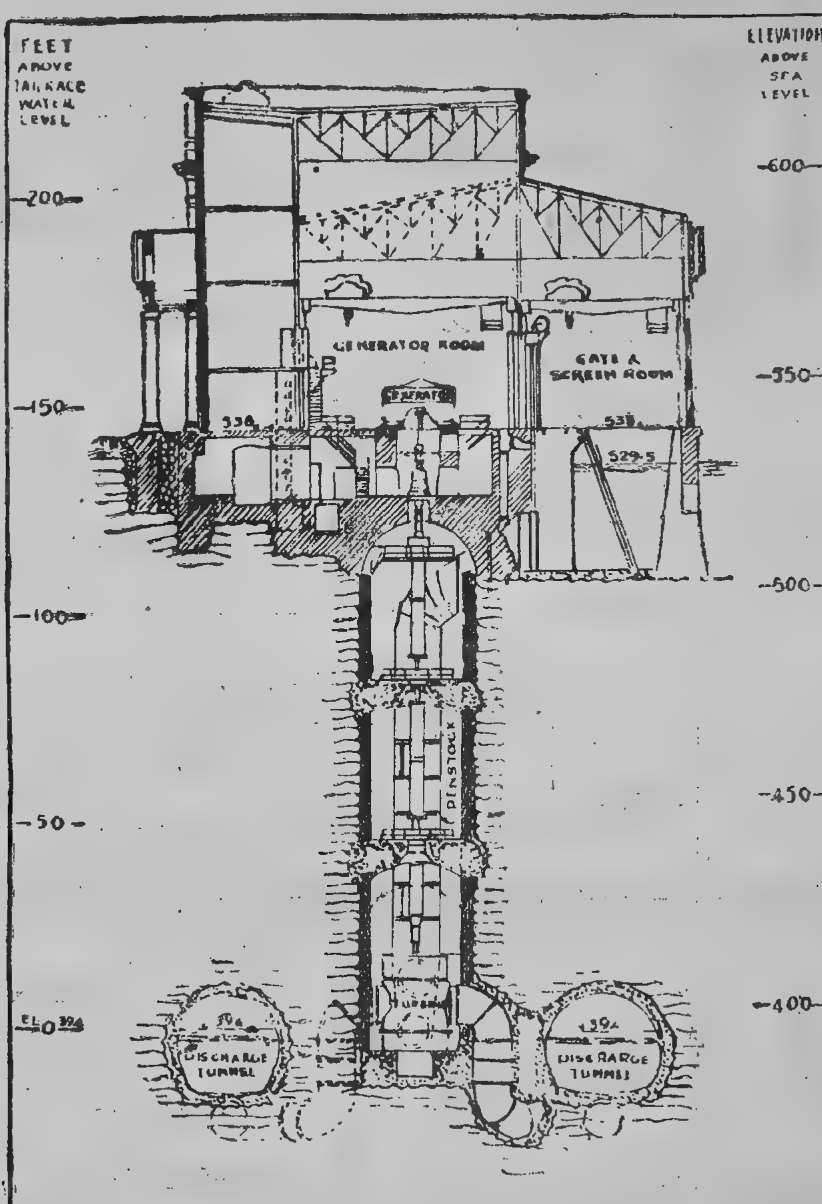
The 60 KV transmission system is Delta with grounding transformer 800 KVA Star.

3.5. *Toronto Power Station.*—The Commission purchased this generating station in 1920. This was designed to utilise the power obtainable in the immediate vicinity of the falls with an average effective head of 135 feet. The generating station is situated close to the intake and the Power-house was built on land reclaimed from the river-bed itself. The ground upon which the Power-house stands was formerly covered with water 8 to 24 feet deep. A cross-section of the Power-house and wheel pit is given in Sketch P.S. 17. The layout of the power station is given in Sketch P.S. 18.

There are 11 penstocks each of length 127 feet and diameter 10 feet 6 inches, almost vertical throughout its entire length. The turbines are vertical double runner reaction type 13,000 to 15,000 h.p. each with a speed of 250 r.p.m. The Power-house is 462 feet long, 91 feet wide and 80 feet high, built of cut stone with steel frame work.

The generators (eleven) are of capacity 8,000 to 10,000 KVA and power is generated at 25-cycles. The voltage of generation is 12 KV.

The tail race tunnel which is 23 feet 6 inches wide, 26 feet $1\frac{1}{2}$ inch high and 2,690 feet long, discharges at the back of the Horseshoe Falls. Power is stepped up to 60 and 110 KV at an outdoor transformer station at the top of the cliff. The 110 KV transformer neutral is grounded through a water rheostat.

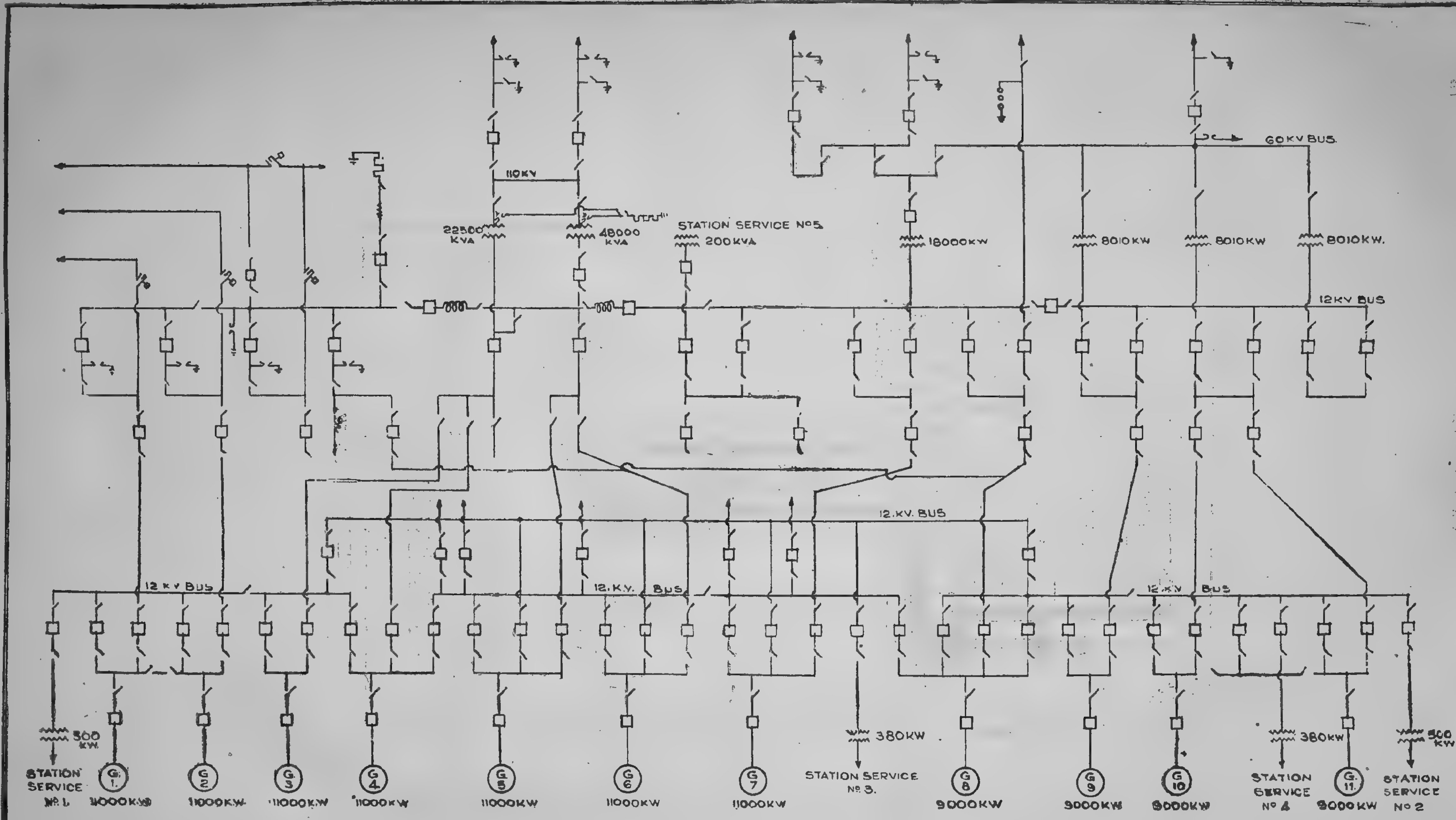


TORONTO POWER GENERATING STATION

POWER HOUSE AND WHEEL PIT

CROSS SECTION

SKETCH P.S. 17.



TORONTO POWER STATION
(H.E.P.C. ONTARIO)

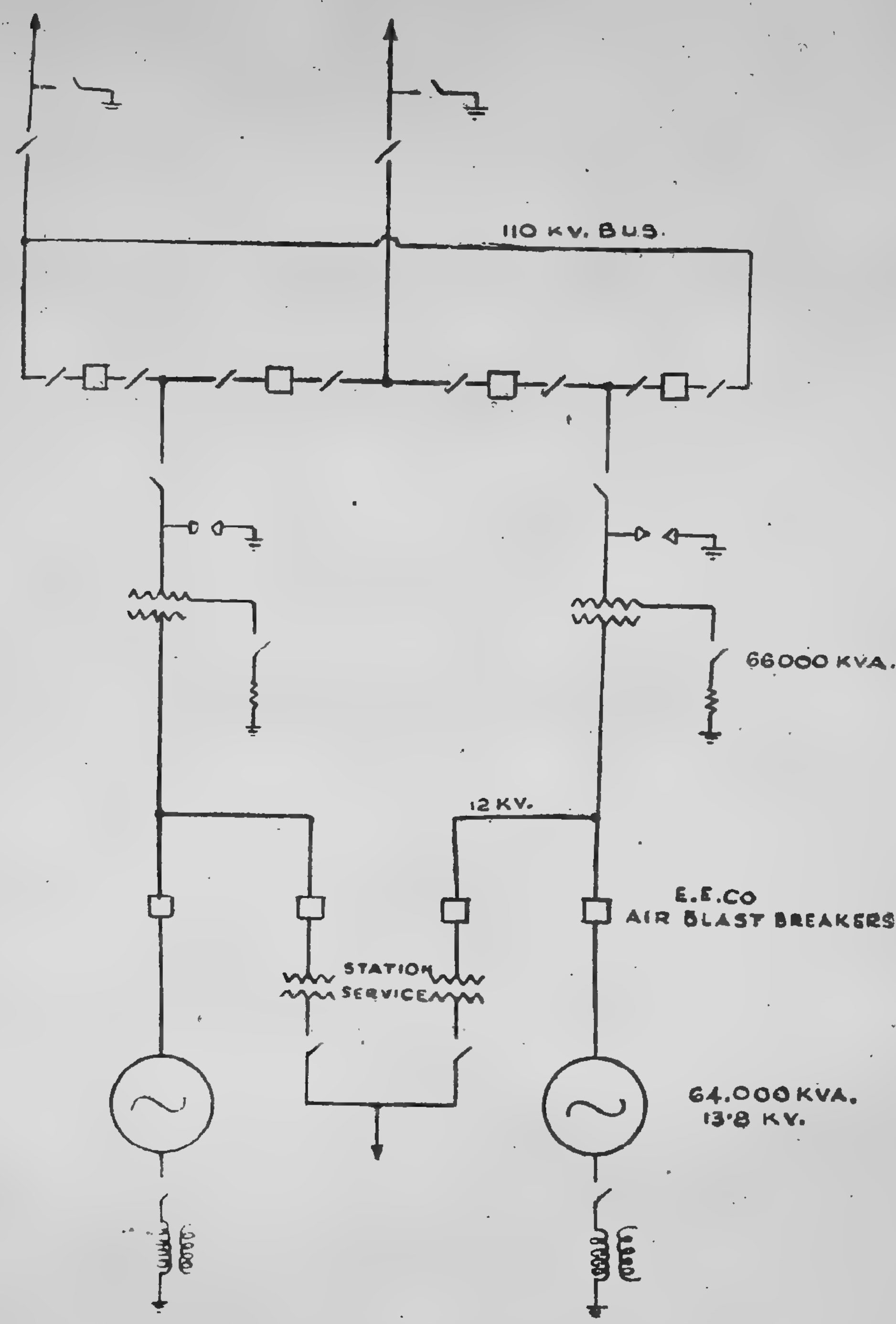
SKETCH. P.S. 18.

3.6. *The Decew Falls Development.*—The 2 Power Plants, Nos. 1 and 2, have an installed capacity of 50,000 h.p. comprising of 9 units and the new plant (No. 2) comprising of 2 units each of 77,000 h.p. are located at Decew Falls on 12-mile creek about 3 miles from St. Katherines. Water for development is drawn from the Welland ship canal at Allenbury and discharges into the lake Ontario at Port Dalhousie.

Power-house No. 1.—There are 9-rivetted steel penstocks installed in 1897.

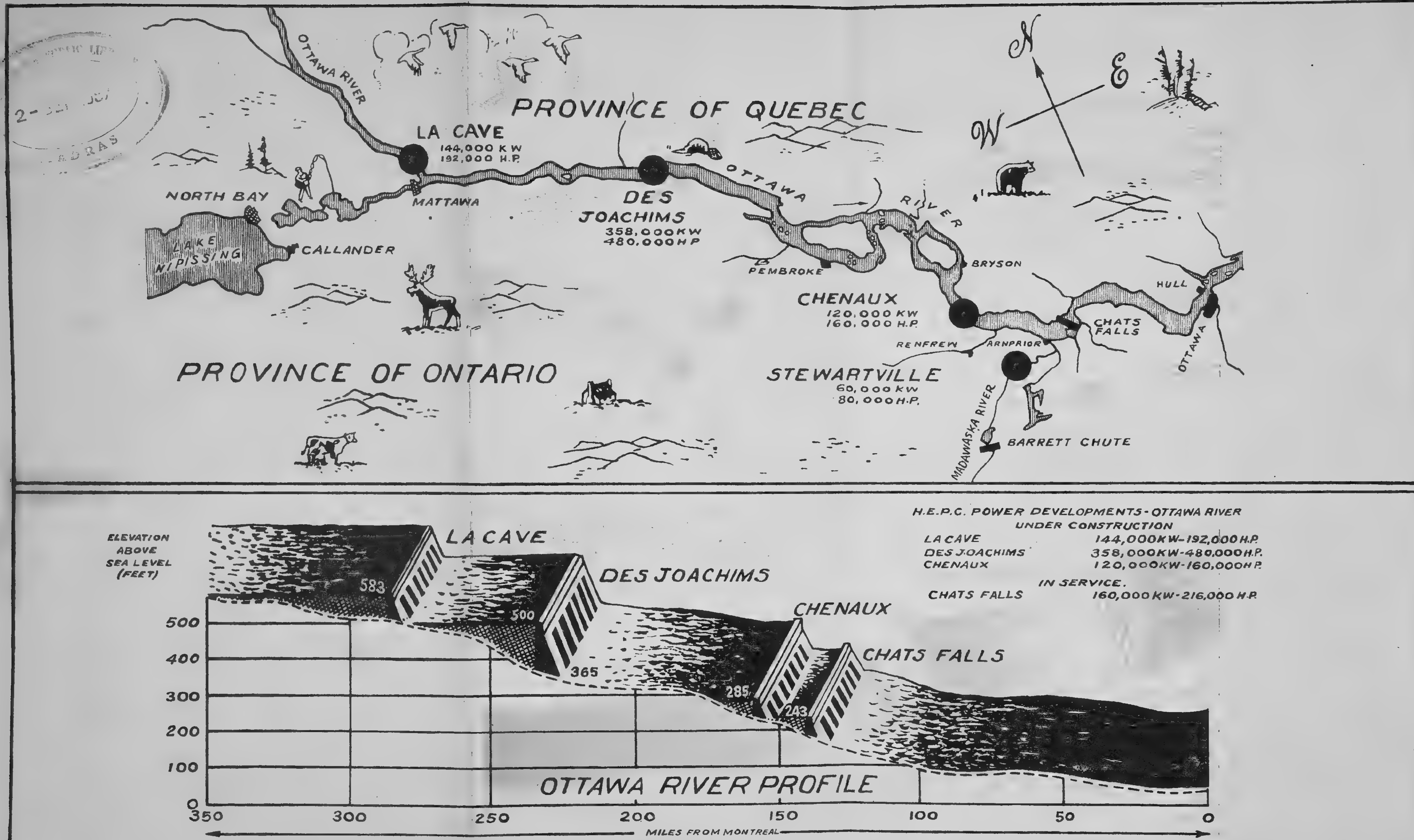
Power-house No. 2.—This operates under a head of 280 feet and contains 2 units each of 77,000 h.p. The penstock 2 in number are embedded in concrete. The turbine one is rated for 150 r.p.m. and the 2nd 166-2/3 r.p.m. Voltage 13,800 V 25 cycles.

The electrical layout of the station is given in Sketch P.S. 19.



ELECTRICAL LAY OUT OF
DECEW FALLS POWER STATION
(ONTARIO HYDRO COMMISSION)

SKETCH.PS.19



HYDRO DEVELOPMENTS IN THE OTTAWA VALLEY AREA

SKETCH P.S. 20.

3.7. *Ottawa River Development.*—The Ottawa river from its source in Quebec flows in a western direction about 180 miles, measured in a direct line, to enter lake Timiskaming close to the Quebec-Ontario boundary, and then generally in a southern and south-eastern direction to its confluence with the St. Lawrence river near Montreal. It has a drainage area of 56,000 square miles and on its 700-mile course has a fall of 1,200 feet. The boundary between Quebec and Ontario follows the river and its lake like expanses from the northern extremity of lake Timiskaming to point Fortune about 22 miles above Montreal island. In the inter-provincial reach of the river, the Ontario Hydro-Electric Power Commission has developed three power sites, viz., Lacave (Ottoholden) about 33 miles below the outlet of lake Timiskaming, Des Joachims a further 60 miles downstream and Chenaux about 11 miles from the town of Renfrew. The discharge is 19,000 to 29,000 cusecs.

To control the water-supply to the conduit or penstock, head gates of the fixed roller type complete with individual hoists, friction and fan brakes are provided. The gates are adopted for push button control for both raising and lowering operations and are arranged for emergency closing from the control room in the event when it becomes impossible to shut down a unit by governor control of the turbine gates. Heating equipment is provided in the gate guides to prevent adherence of ice to cheeks, rollers, or roller paths under the most severe winter conditions.

Motor-operated travelling gantry cranes are provided at the headworks for placing the emergency steel stop logs to dewater the supply conduits while repairs are made to the head gates. The gantries have adequate capacity for handling the head gates and are also used for changing trash racks. Similar facilities are provided for the tail race bays to unwater the draft tubes.

Power-house sump pumps and draft tube dewatering pumps are permanently installed in pits together with a permanent system of piping and valves to allow dewatering of draft tubes when the tail race gates are installed.

The Lacave (Ottoholden) Development has a total capacity of 8 units of 257,000 h.p. operating under a normal head of 77 feet. Des Joachims is the largest of the three stations and operates under a developed head of 135 feet, having a total capacity in 8 units of 480,000 h.p. The Chenaux development operates under a relatively low head of 40 feet and has a total capacity in 8 units of 160,000 h.p.

These are downstream from Lacave with a number of large storage basins which effectively regulate the flow of the river. These have a total storage capacity of nearly 5 million acre feet.

The plan and profile of the hydro-developments in the Ottawa valley area are shown in Sketch P.S. 20.

3.7.1. *Des Joachims Generating Station—Ottawa River.*—This is the largest of the 3-new developments on the Ottawa river with 8 units of a total capacity of 358,000 KW. The project is located on the main river at the Rapide Des Joachims.

The scheme comprises essentially the main dam, power-house, a tail race channel, the Mcconnell lake control dam, side dams, and a flood discharge channel for passing high river flows.

The headworks consists of 8 separate intakes. Water from the bay enters each intake through two openings which merge before reaching the penstock. Racks are provided in each opening and are placed upstream from the face of the dam, so that any water-logged roots or logs may be pushed below the intake. For dewatering the headgates, steel emergency stop logs may be placed downstream from the trash racks. Headgates are provided for each intake and each headgate is equipped with an independent hoisting mechanism

driven through suitable gearing from an electric motor. The hoisting mechanism is housed in a reinforced concrete superstructure 480 feet long, 17 feet wide and 13 feet high situated on the downstream side of the headworks deck. On the headworks deck, outside the superstructure, an electrically operated gantry crane 40 tons capacity is provided for handling the headgates, emergency stop logs and trash racks. An auxiliary hook of higher speed with a capacity of 4 tons is also provided for handling trash.

Eight steel penstocks 22 feet in diameter and 140 ft. in length encased in concrete convey the flow from the headworks to the turbines in the power-house substructure at the base of the dam.

The power-house is located at the base of the downstream side of the dam. The lower elbow, the penstock and the steel plate scroll case are encased in the concrete substructure. The water after passing through the scroll case and turbine enters concrete elbow type draft tubes and then passes into the tail race. Each draft tube may be dewatered by placing a set of steel stop logs between the tail race piers deck. For dewatering, the draft tubes are drained into sumps provided between each pair of units with pumps which discharge in the tail race channel.

Eight vertical shaft generating units each comprising a francis turbine directly connected to a conventional generator, operate at 105·9 r.p.m. Each turbine is rated 62,000 horse-power at 130 feet head. The switchyard is located south-east from the erection bay. Circuit breakers, relay, telephone, oil storage tanks, control duct line and piping are located within this yard. Carrier communication and relaying are provided on 230 KV circuits.

The Sketch P.S. 21 gives the electrical layout of the station and P.S. 22 the operating diagram.

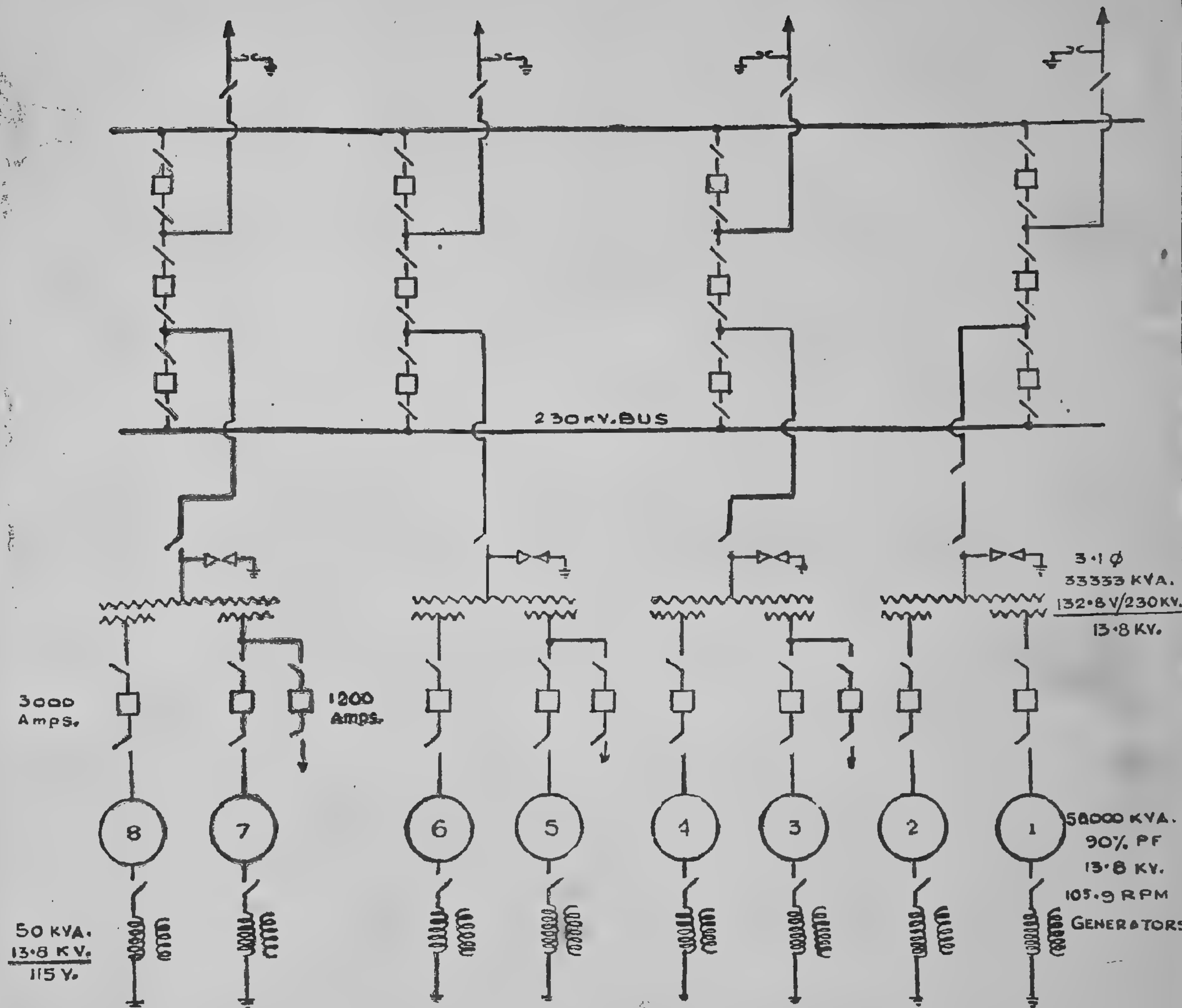
The generators, i.e., 50,000 K.V.A. 0·9 P.F. 13·8 K.V. 60 cycle machines, with modern square casing and air circulated by fans and cooled by water in 8 cooling coils mounted on generator frame.

The machine and electrical shops, storage rooms and station service are located on the generator room floor level in the one storey section of the building between the generator room and the downstream face of the dam. The battery, cable, bench, locker and wash rooms are at the southerly end of the power-house on the generator room floor level of the section of the building between the generator room and the downstream face of the dam, with the control room, reception wing and offices in the two upper floors.

The 13·8 K.V. power from each generator is conducted by copper busses in metal compartments through a 3,000 ampere air blast circuit breaker in a metal-clad structure, thence through single conductor cables to the main transformer bank. Each bank consists of 3-33, 333 KVA (3 Nos. 33,333 KVA) single phase water cooled transformers connected Delta-Star with the neutral of the star solidly grounded. Each transformer has two low voltage windings to receive the output independently from each of the two generators. This results in an arrangement of 4 main transformer bank on the tail race deck to serve the eight generating units.

The switch yard is located south-east from the erection bay. This contains 14-230 KV 800 amp. 5,000 MVA rupturing capacity pneumatically operated O.C.Bs., each with its own air compressor and storage tanks. Twelve circuit breakers are arranged for 3 pole reclosure and the other two for single pole tripping and reclosure. The 230 KV ring bus is on the basis of one and half breaker per element.

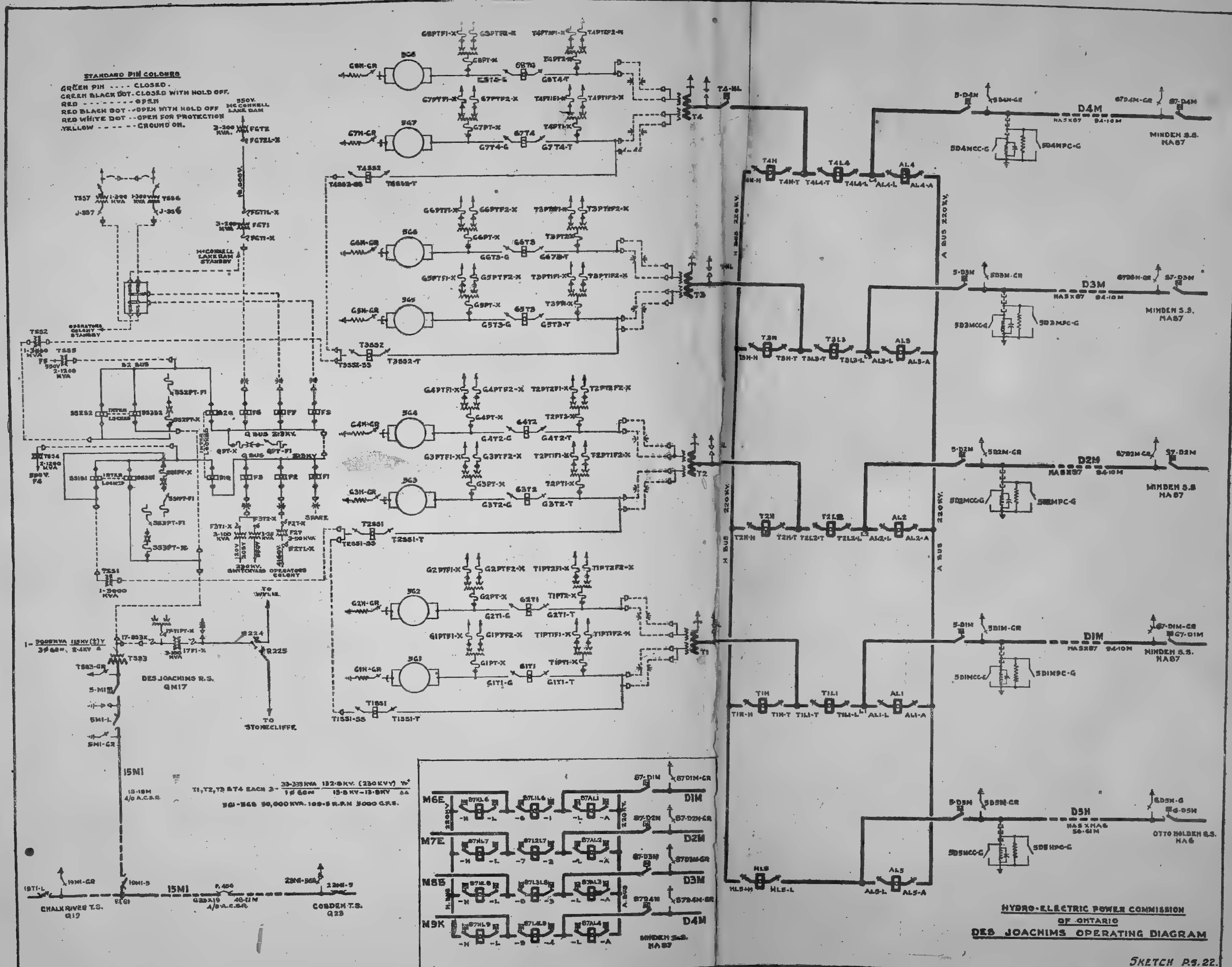
Relay, telephone and oil treating buildings, oil storage tanks, control duct lines and piping are located within this yard. Carrier communication and relaying are provided on 230 KV circuits.



ONTARIO H.E.P.C.

DES JOACHIMS GENERATING STATION

SKETCH. D.S. 21.



STANDARD PIN COLOURS
GREEN PIN ---- CLOSED.
GREEN BLACK DOT - CLOSED WITH HOLD OFF.
RED ---------- OPEN
RED BLACK DOT - OPEN WITH HOLD OFF
RED WHITE DOT - OPEN FOR PROTECTION
YELLOW ------- GROUND ON.
McCONNELL LAKE DAM
McCONNELL LAKE DAM STANDBY
OPERATORS COLONY STANDBY
Q BUS 2.3KV.
B2 BUS
SPARE
SWITCHYARD
OPERATORS COLONY
TO WYLIE
TO STONECLIFFE
DES JOACHIMS R.S.
QN17
15M1
CHALK RIVER T.S.
Q13
COBDEN T.S.
Q23
T1, T2, T3 & T4 EACH 3 - 33-333 KVA 1φ 60~ 132.8KV. (230KVY) 13.8KV - 13.8KV
SG1 - SG8 50,000 KVA. 103.5 R.P.M. 3000 C.P.S.
H BUS 220KV.
A BUS 220KV.
D4M
D3M
D2M
D1M
D5H
MINDEN S.S.
NA67
OTTO HOLDEN G.S.
NA6
M6E
M7E
N8B
N9K
HYDRO-ELECTRIC POWER COMMISSION
OF ONTARIO
DES JOACHIMS OPERATING DIAGRAM
SKETCH P.S. 22.

3.7.2. *Chenaux Generating Station (Ottawa River).*—This station takes advantage of the natural fall in the Ottawa River from the outlet of the Bryson channel to Chats-falls lake. The scheme included the construction of a lake 7 miles long and 1 mile wide with an area of 4,600 acres and clearing of 2,100 acres of land.

Headworks.—The headworks, 500 feet in length, consist of eight separate intakes each of which is divided into three passages. The headworks are built integrally with the power-house and water from the head pond passes through the intake directly into the concrete scroll case of the unit. Each passage is protected against debris by trash racks and the flow of water can be shut off by means of steel headgates and emergency steel stop logs. The hoists for the headgates are located in the headgate gallery. A travelling gantry on the headworks deck, equipped with 25-ton and 4-ton lifting hooks is used to service this equipment.

Power-house substructure.—The Power-house is located immediately downstream from the headworks. For each of the generating units, the concrete volute scroll case forms a continuation of the intake structure. The entrance to the turbine gates are formed by truncated conical sections protruding from the floor and ceiling. This type of construction provides an even flow of water to the propeller type turbine runners. After passing through the turbine, the water flows through the elbow type concrete draft tubes and discharges into the tail race. Each draft tube can be dewatered by lowering the steel stop logs between the tail race piers and pumping the water through drain pipes connected to deep well sump pumps.

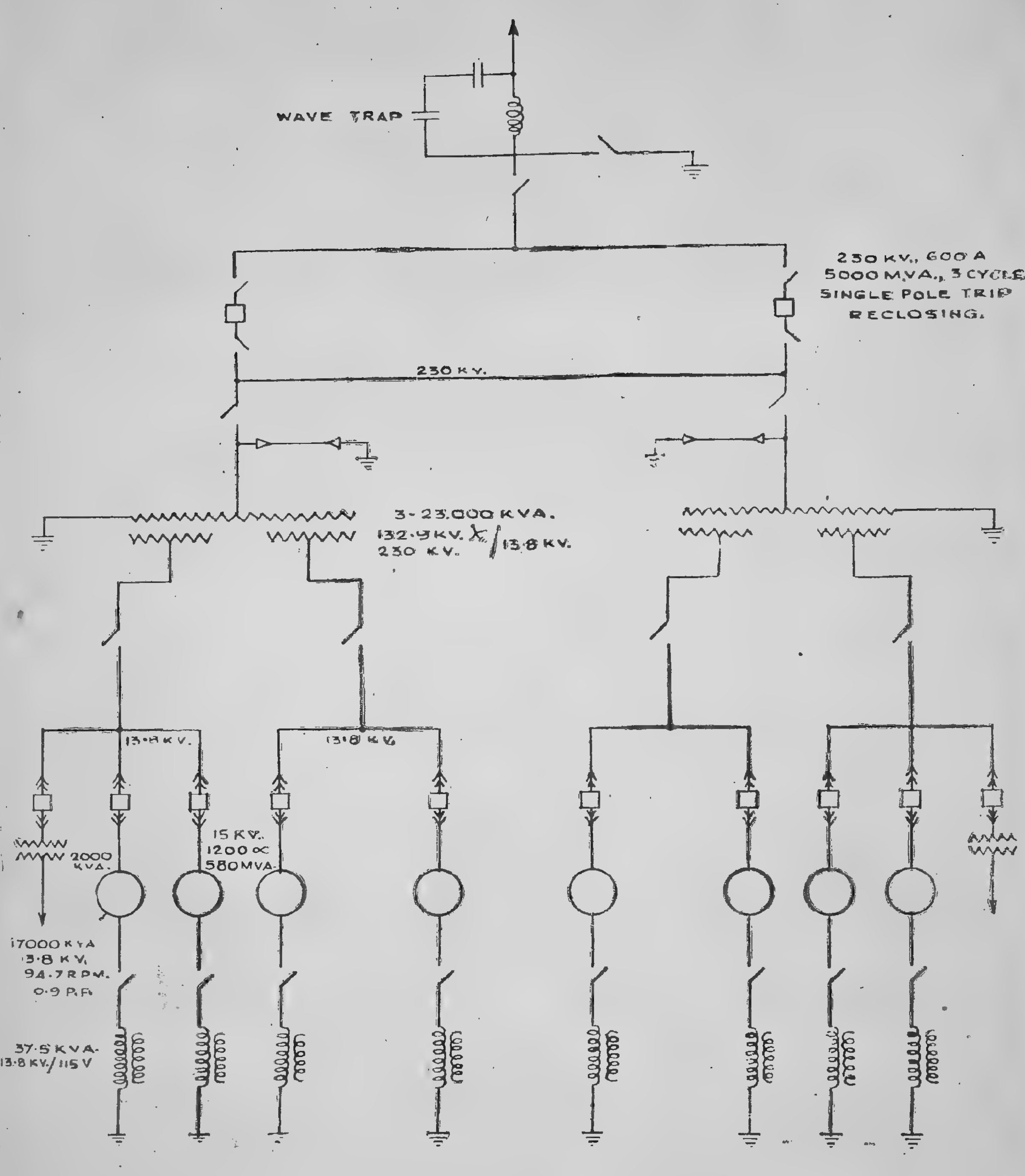
A 20-ton capacity travelling gantry crane on the tail race deck is used to place stop logs in position.

Extending throughout the substructure immediately above the scroll cases is the turbine floor, on which are located the sump tanks for the governor servo-motors, amplidyne and low voltage station equipment, oil, water and air controls. On the down stream side are three galleries to carry cables and equipment.

Generating equipment.—Eight vertical shaft generating units each comprising of a fixed blade propeller type turbine directly connected to a conventional type generator operate at a speed of 94·7 r.p.m. Each turbine has a rated capacity of 21,000 h.p. at 40 feet head. The governors are of the twin cabinet type, situated upstream and entirely placed between each pair of units. The governor pressure system includes pressure tanks and sump tanks which are inter-connected in pairs to form twin system. Operation of the pump is controlled so that one pump supplies both the pressure tanks at normal pressure, while the other functions only when pressure falls to a predetermined value below normal.

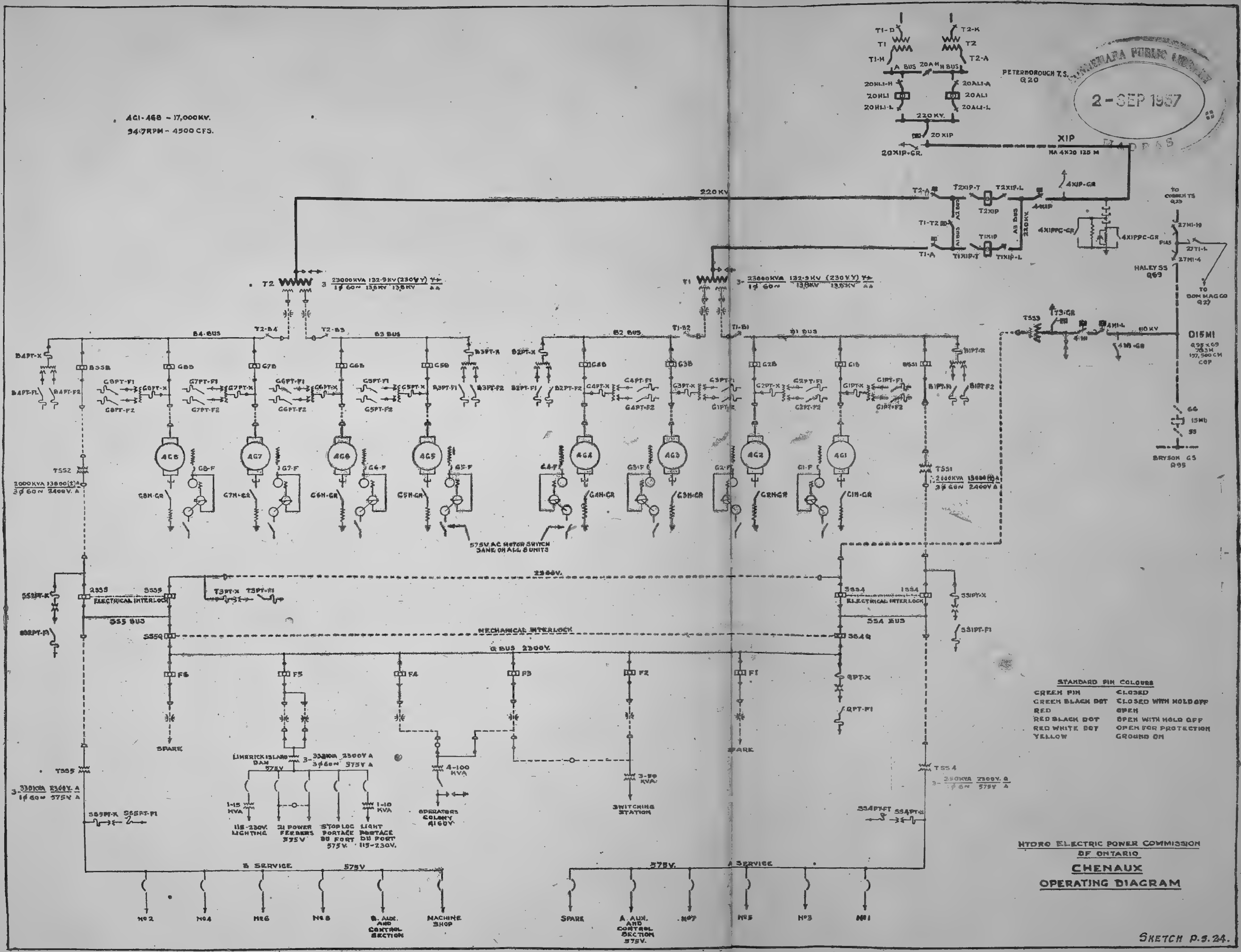
The generators are 17,000 K.V.A. 0·9 P.F. 3 phase 60 cycle 13·8 K.V.

Sketch P.S. 23 gives the electrical layout and Sketch P.S. 24 the operating diagram of Chenaux Station.



CHENAUX

SKETCH. P.S. 23.



4G1-4G8 ~ 17,000KV.
94.7RPM ~ 4500 CFS.
PETERBOROUGH T.S. Q20
XIP
220 KV.
T2
T1
B4 BUS
B3 BUS
B2 BUS
B1 BUS
D15M1
110 KV
HALEY SS Q69
BRYSON GS Q95
575V. AC MOTOR SWITCH SAME ON ALL 8 UNITS
2300V.
ELECTRICAL INTERLOCK
SS5 BUS
SS4 BUS
MECHANICAL INTERLOCK
Q BUS 2300V.
SPARE
LIMERICK ISLAND DAM
OPERATORS COLONY
SWITCHING STATION
B SERVICE 575V
A SERVICE 575V.
MACHINE SHOP
B. AUX. AND CONTROL SECTION
A. AUX. AND CONTROL SECTION 575V.
STANDARD PIN COLOURS
GREEN PIN — CLOSED
GREEN BLACK DOT — CLOSED WITH HOLD OFF
RED — OPEN
RED BLACK DOT — OPEN WITH HOLD OFF
RED WHITE DOT — OPEN FOR PROTECTION
YELLOW — GROUND ON
HYDRO ELECTRIC POWER COMMISSION OF ONTARIO
CHENAUX
OPERATING DIAGRAM
SKETCH P.S. 24.

Supply to the auxiliaries at Chenaux Station.—Supply is tapped off the generator bus, one at each end and they supply the auxiliaries of 1, 3, 5 and 7 units and 2, 4, 6 and 8 units respectively. They are interlocked either electrically or mechanically so that they cannot be paralleled on the L.T. side of the transformers.

In addition, supply is availed from an external source by a 2,000 KVA, 110 KV/2,400 V. transformer which will feed into the auxiliary bus in case of total A.C. failure to the station.

This transformer has single pole grounding switch and a motor operated 3-pole disconnecting switch so that in the event of any fault on this transformer, the grounding switch will close and trip the breaker at the other end of the line. *Six seconds after the closing of the grounding switch, the disconnecting switch will open and keep the line free for the O.C.B. at the remote end to be closed.*

All the 13·2 KV and 2·4 KV breakers on the auxiliary power board are of the air break type. The incoming and the bus breakers are electrically operated from the control board. All feeder breakers (575v) are manually operated.

3.7.3. *Chatsfalls Power Station*—

Area drained—34,000 square miles.
Maximum flow—45,000 cusecs.
Minimum flow—22,000 ,,
Minimum recorded flow—11,000 cusecs.
Maximum recorded flow—200,000 ,,
Area of the Chat lake—27 square miles and this provides local pondage to store for daily and weekly variations in load.

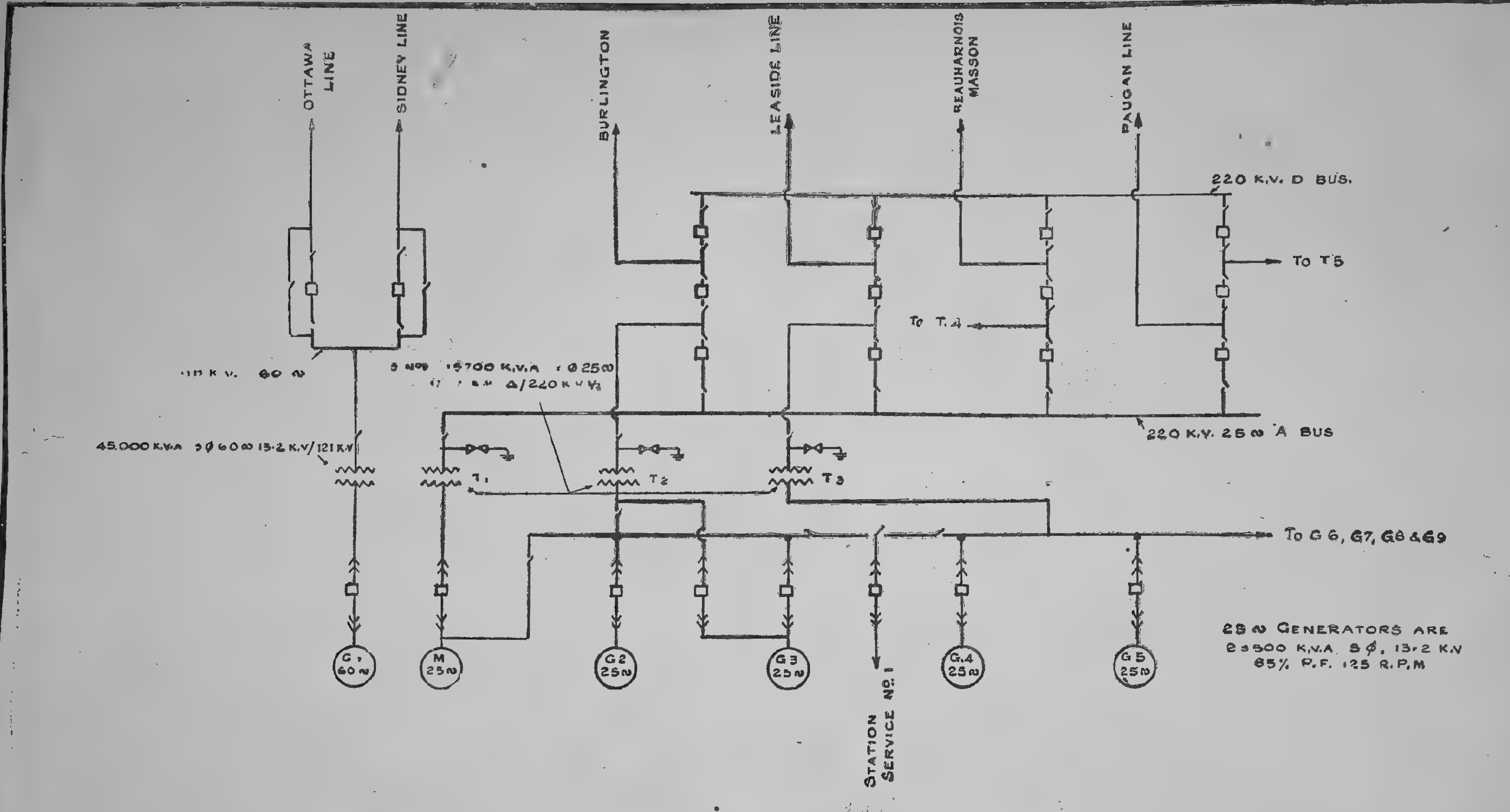
The Chat-falls power site includes the fall in the Ottawa river between Chats-lake and lake Des Joachims and has a fall of 38–58 feet. The scheme involved the construction of a dam U-shaped in plan extending approximately one mile upstream on either mainland to reach the supporting contours.

To ensure operation under low temperature conditions, the gates are closed in the down stream side and heated with electric space heaters. The cheeks are also protected by electric heaters in vertical chambers located in the piers adjacent to the roller paths and sealing rods and forming part of the embedded cheek steel. The head gates close an opening of 15 feet width and 23 feet high and are of the fixed roller type. Remote control apparatus enables them to be lowered from the control room.

The head-works or intake section of the power house is incorporated in the main dam. There are three outer-passages per unit, each of 15 feet × 40 feet to the underside of the curtain wall. Immediately downstream are located the trash racks. The racks are supported in steel lined cheeks. There are three spare sections of the racks and sufficient emergency gates for one unit. In case, it becomes necessary to remove racks for cleaning, the three spare sections may be dropped into the emergency gate cheeks immediately down stream from the rack cheeks thus protecting the opening while the regular racks are removed. The power house substructure is constructed entirely of R.C.C. in which are formed the draft tube, scroll case and generator air ducts. The draft tubes are of the elbow type and extend 30 feet down stream from the power house wall or 60 feet from the centre line of units. The lowest point of the draft tube is about 38 feet below normal tail water level sloping up 3·6 feet at the down stream end. The draft tube is 10 feet 6 inches in height at its lowest elevation.

There are eight generating units at this station operating between 38—58 feet head. The turbines are of Dominion Engineering Company make rated for 28,000 h.p., each discharging 5,300 cusecs and running at 125 r.p.m. The runner is of propeller type with six blades and is of cast steel and of specific speed 146. Each unit is coupled to a 23,500 KVA Westinghouse air cooled generator. The spacing between the units is 62 feet. The electrical layout of the station is given in Sketch P.S. 25.

The generator neutrals are ungrounded.



ELECTRICAL LAY-OUT OF CHATS-FALLS GENERATING STATION

(H.E.P.C. ONTARIO)

SKETCH. P.S 25

Control and Switchboard.—The control of all electrically operated equipment in the power house and transformer station is centred in the control room located at the centre of the power house. The system adopted allows a compact arrangement of control and indication which is advantageous for operation and suitable for the limited width of the control room.

A vertical indicating meter board combined with a control desk having 95 controllers has been installed (Miniature 48-V).

Controllers operate inter-posing relays which in turn operate the equipment from a 250-V. DC System. The power supply for this control system is obtained from a 250 volts D.C system consisting of storage batteries of the sealed top type.

Duplicate 250-V. and 48-V. batteries are installed with M.G. set for each battery as well as duplicate control busses. One 250-V and one 48-V battery are located in each of the rooms with the controlling switch-board and four charging sets in a centre room. Suitable switching facilities for transferring either of the batterys to its respective chargers and to control bus are provided. The control room is 18 feet × 40 feet and contains the generator regulator boards, the totalizing meter board and the generator ground detector and annunciator board.

Directly below the control room is the terminal room in which as the name implies, all cables to the control room terminate. Here is located the switchboard for the generator and transformer bank standby relays.

A generator switchboard is adjacent to each generator. On each switch board are mounted the main and exciter field breakers, the regulator contactors, the recording meters, temperature indicators, interposing and protective relays and lighting switches. Near one end of each switchboard is installed the motor operated exciter field rheostat. In the transformer terminal, directly below the centre transformer of each bank, is a two panel board for the transformer relays and the temperature indicating instruments.

In the case of the 220 K.V. switch, the relay building is in the yard and in this building is installed a switchboard containing all line, 220 K.V. bus, transformer high voltage zone and interposing relays as well as 250-V control switches.

Structures.—Galvanized steel structures 12 feet between phase and 7 feet 6 inches between phase and ground are used. For all strain busses on which tap connections were not required, 795,000 C.M. steel reinforced aluminium cable is used, the balance of the strain busses and taps being hollow conductor copper cable having a conductivity of 750,000 C.M. The rigidly supported bus is 2 inches I.P.S. copper tubing.

All bus connections are clamped except the connexion of aluminium cable to copper terminals which are of the compression type.

Cables.—Two single conductor cables per phase connect generators to bus and four similar cables per phase connect bus to transformers. These are P.I.L.C. rated for 15 K.V. service. Extensive saving in building costs without increase in equipment costs was obtained by using cable for these connexions over that required by a rigid bus mounted on porcelain insulators. With the latter type of construction, it would have been necessary to increase the width of the power house and also increase the size of the transformer terminal.

The 13·2 K.V. system is designed so that in case of insulation failure, two grounds must occur before a short circuit results.

All cable runs are made with complete lengths of cables in order to eliminate the possible weaknesses of cable joints, the greatest run being 600 feet approximate.

Instead of constructing a delta bus at the transformer, the single conductor cables connecting the bus to the transformers form the delta.

Station service power.—The power supply for the operation of all auxiliaries for the power station and transformer station is obtained from two service transformer banks installed on the gallery one in each half of the generating station. Inter-connections are provided so that all service loads may be carried by either bank. The banks are enclosed in separate fire proof rooms each with a carbon dioxide fire protection system which is fully automatic.

3·8. *Pine Portage Development.*—This is situated on the Nipigon River about 12 miles upstream from Cameron Falls Generating Station.

The project comprises of a gravity type concrete dam approximately 3,100 feet long with maximum height of 140 feet in which the intake spillway and log chute, head block, etc., are incorporated ; a flood water channel below the spillway, a power house immediately down stream from the dam on the west bank of the river and a tail race channel 600 feet long carrying the discharge from the draft tube to the Nipigon river.

The headworks section consists of four intakes, one for each unit. Water from the forebay enters each intake through two openings which merge before reaching the penstocks. Steel trash racks are installed on the upstream face of the head works. Head gates controlled by separate motor driven hoists are provided for each intake.

The penstocks are 20 feet in diameter with a thickness of 3/4 inch throughout. They are encased in concrete envelopes having a minimum thickness of about 18 inches. The purpose of the concrete envelope is to protect the steel, eliminate periodical maintenance and prevent expansion and contraction of the penstocks due to large variations in temperature.

The Power House is a steel and concrete structure 175 feet by 60 feet and is located close to the face of the dam. Two single runner vertical shaft Francis turbines each with a limited capacity of 41,000 h.p. under a head of 105 feet at 109·1 r.p.m. controlled by Woodward governors, are installed.

The water discharged from the turbines passes through concrete type elbow draft tubes to the tail race below the Power House. Draft tubes have been constructed for the third and fourth units that will be installed at some future date.

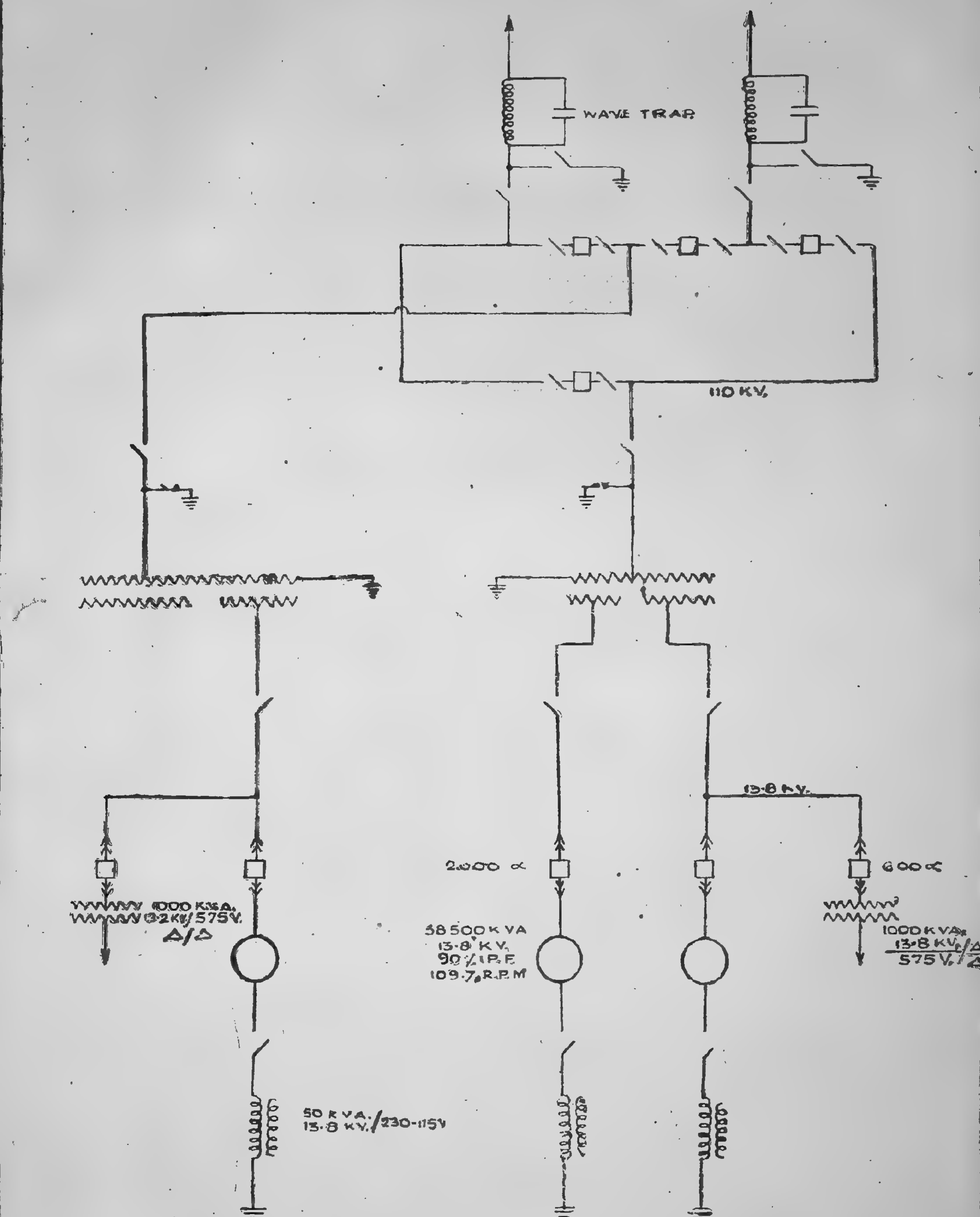
The generators are rated 33,000 K.V.A. at 90 per cent p.f., 13·8 K.V. They are of the umbrella type and totally enclosed. Rototrol type of regulators are used in these generators.

The transformer bank is installed immediately west of the Power House. This comprises of 3 transformers each 22,000 K.V.A. single phase 13800V/138 K.V. star. A fourth transformer has been provided for use as spare.

The low voltage switching equipment supplied by the English Electric Company is of the air blast type.

The control room is located in the main floor. The floor above the control room provides accommodations for office, storage, etc.

The electrical layout of this station is shown in Sketch P.S. 26.



PINE PORTAGE.

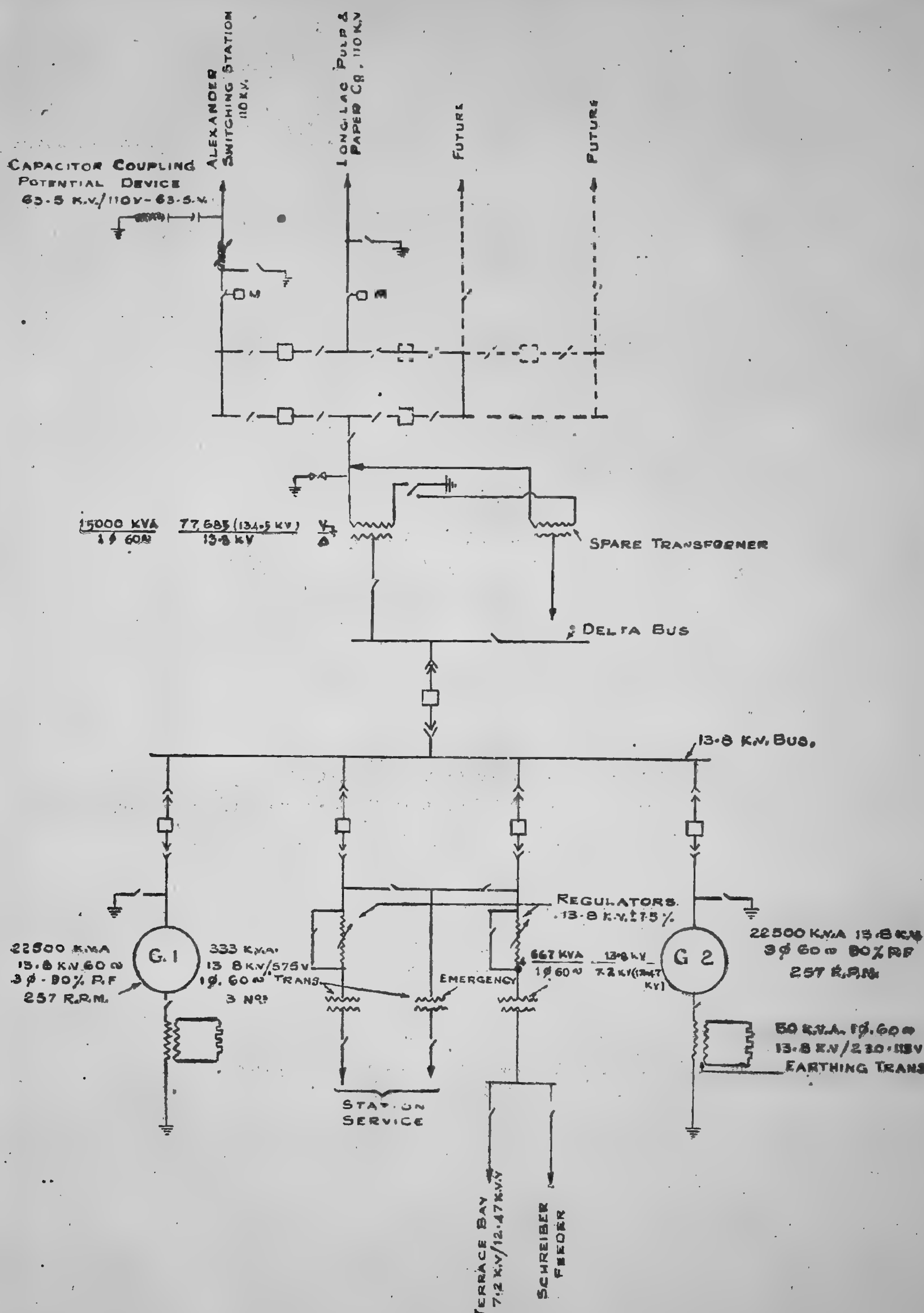
SKETCH. RS. 26.

3.9. *Aguasabon Generating Station.*—This scheme involves the construction of a dam, intake structure and the generating station all widely separated. A 3,500 feet tunnel through solid rock, to convey water from the intake structure to the power-house, enlargement of a small lake to 500 times its original size to create the head pond for the development, etc., are some of the important features.

About 12 miles above its outlet to the lake Superior, on the main dam is situated Aguasabon and is about 1,400 feet long with a maximum height of 120 feet from solid rock.

Another striking feature is the 240 feet steel surge tank located on hill about 480 feet from the power-house and directly above the tunnel. The tank is 32 feet in diameter and 90 feet high and is set upon a 150 feet structural steel tower. Connexion is made with the tunnel below by means of a steel pipe 15 feet in diameter which extends downwards 150 feet from the bottom of the tank to the ground surface, thence through 100 feet of rock shaft to the tunnel.

The electrical layout of the station is given in Sketch P.S. 27.



ELECTRICAL LAY-OUT OF AGUASABON GENERATING STATION (H.E.P.C. ONTARIO)

SKETCH P. S. 27

3.10. 1. *Technical Characteristics of generating stations.*—The technical characteristics of the generating stations

TABLE 2

Name of station.	*Lacave.* (Otto Holden.)	*Des Joachims.*	*Chenaux.*	*Stewart Ville.*	*Chats Falls.*
	(..................Ottawa River Developments				..................)
1 Date of installation	1950/52	1950/51	1950	1948	1933
2 Total discharge in cusecs	18,800	20,700	23,050	6,500	45,000
3 Number of units installed	8	8	8	3	8
4 Discharge per unit in cusecs	4,500	4,950	5,000	..	5,300
5 Length of penstock in feet	..	195	..	227	..
6 Material of penstock	Concrete	Steel	Concrete	Steel	Concrete.
7 Diameter of penstock	..	22	..	14	..
8 Number of supply conduits per unit	2	1	1	2	3
9 Number of penstocks	..	8	..	3	..
10 Head in feet	77	130	40	148	38–58 feet
11 Type of inlet valve	..	..	..	..	..
12 Make of turbine	4-Allis Chalmers 4-E.E.Co.	Dominion	Engineering.	Allis Chalmers.	Dominion.
13 Type of turbine	Reaction.	Reaction.	Fixed blade propeller.	Reaction.	Fixed blade propeller.
14 Rating of turbine (H.P.)	34,400	62,000	21,000	28,000	28,000
15 Speed (R.P.M.)	94·7	105·9	94·7	163·6	125
16 Make of generator	Westinghouse.	Westinghouse.	C.G.E.	C.G.E.	Westinghouse.
17 Rating of generator (K.V.A.)	27,000	50,000	17,000	24,000	23,000
18 Thrust bearing type	Kingsbury pivotted pad:	Kingsbury pivotted pad.	Spring type.	Spring type.	Kingsbury.
19 Whether above or below rotor	Umbrella	Conventional.	Conventional.	Conventional.	Conventional.
20 Runaway sped (R.P.M.)	170	195	210	280	260
21 WR^2 of the unit	$39·0 \times 10^6$	60×10^6	$24·0 \times 10^6$	$10·0 \times 10^6$	18×10^6
22 Length of the P.H. in feet	..	590	..	..	499
23 Width of the P.H. in feet	..	58	..	..	70
24 Height of the P.H. in feet	..	65	..	..	53
25 Spacing between units in feet	..	60	62	..	62
26 Number of floors	..	4	4	..	
27 Difference in level between centre line of distributor and minimum tail level–feet	..	8	4·5	2	5
28 Neutral of the generating unit	Grounded through 50 K.V.A. transformer.	Grounded through 50 K.V.A. transformer.	Grounded through 37·5 K.V.A. transformer.*	Gounded through 25 K.V.A. transformer.	Insulated.
29 Transformer H.T. neutral	Solidly grounded.	Solidly grounded.	Solidly grounded.	Solidly grounded.	Solidly grounded.
30 Regulating constant $C = \frac{WR^2 \times n^2}{HP}$	$10·6 \times 10^5$	$10·7 \times 10^5$	$10·2 \times 10^6$	$9·55 \times 10^6$	..
31 Inertia constnant $\frac{0·231\ WR^2 \times n^2}{KVA \times 10^6}$	2·99	3·09	2·92	2·58	2·82
32 Capacity of the P.H. crane	2 × 100 tons.	2 × 170 tons.	2 × 100 tons.	120 tons.	2 × 90 tons.
33 Cost in millions of dollars	55·0	75·8	29·8	16·4	..
34 Remarks.—					

* The resistor is 367 amps. 36 ohm. 5 min. rating.

of the Hydro-Electric Power Commission of Ontario are given in the table below :—

Niagara No. 1.	*Niagara No. 2.*	*Ontario.*	*Toronto.*	*Pine Portage.*	*Decew Falls.*	*Aguasabon.*	*Earfalls.*
Niagara River Developments		.. .. ..)			Well and River.		
1922–25	1950–54	1902	..	1950	1947	1948	1929–48
14,000	40,000	..	..	..	..	..	..
10	12	16	11	2 present 4 ultimate.	2	2	4
..	..	..	..	..	2,700	..	..
383	..	..	..	170	402	1,300	
Steel.	Steel.	Steel.	Steel.	Steel.	Steel.	Steel.	..
16 feet	..	9	..	20	16·5	16	..
..	..	1	1	2	1	..	..
10	12	16	11	2/4	2	1	4
294	294	175	135	105	280	290	38
Johnson valve.	..	..	Head gates serve as inlet valves.	Head gates only.	Head gates only.	..	..
..	..	..	William Cramp.	Allis Chalmers.	Allis Chalmers.	Dominion Engineering.	..
Vertical Reaction.		Horizontal twin reaction.	Vertical reaction.	Vertical reaction.	Vertical reaction.	Reaction.	2 Fixed blade. 2— Kaplan.
55,000/58,000	105,000	..	7—15,500 4—13,000	41,000	77,000	27,500	[2 — 5,000 H.P. (F.B.). 2—7,500 (Kaplan).
187·5	150	187·5	250	109·1	150	257	180—F.B. 150—Kaplan]
..	6—G.E. 6—Westinghouse.	..	..	Westinghouse.	General Electric.	Westinghouse.	..
45,000 50,000	80,500	30,000 (K.W.).	..	33,000	64,000	22,500	4,800—6,000
..	..	..	..	Kingsbury pivotted pad.	Kingsbury, spring type.	..	..
..	G.E.—Conventional. Westinghouse—Umbrella.	..	..	Conventional.	Conventional.	Conventional.	..
345	250	..	..	215	310	500	..
$21{\cdot}7 \times 10^6$	$45{\cdot}0 \times 10^6$	..	..	$40{\cdot}3 \times 10^6$	..	$4{\cdot}9 \times 10^6$	..
590	..	..	..	175	..	..	..
135	..	..	..	60	..	..	..
180	..	..	..	..	..	..	..
60	..	..	..	60	48	35	..
9	..	..	..	4	..	5	..
9	..	15	..	7	7	4·7	..
Insulated.	Grounded through 25 KVA Transformer.	Insulated.	Insulated.	Through 50 KVA. transformer.	Through a potential transformer.	† Through 50 KVA transformer.	..
Through a water rheo.	Solidly grounded.	(Through a water rheostat.)		Solidly grounded.	Through a water rheo.	Solidly grounded.	..
..	..	..	..	$10{\cdot}5 \times 10^6$	$9{\cdot}170 \times 10^6$	..	..
3·51	2·77	..	..	3·20	3·32	..	..
..	..	..	..	180 tons.	..	100 tons.	..
..	..	..	..	26·3	..	16·5	..
2 auxiliary units 2,200 K.V.A. 80 per cent p.f. 500 RPM are provided.	..	Relief valve is provided.	..	..	Relief valve is provided.	..	..

† Resistanc 0·22 ohms.

TABLE 3.

	Head. FT.	Installed capacity.	Type.	Generators.	Exciters.	R.P.M.	Hs. FT.	Remarks.
1 Nipigon ..	78	6 × 12,500 h.p.	Vertical Francis reaction.	6 × 10,600 K.V.A.	105 K.W.	120	7	Penstock scroll case draft tube (concrete).
2 Alexander ..	58·8	3 × 18,000 h.p.	Francis vertical.	3 × 15,000 K.V.A.	..	100	9	Do.
		1 × 19,000 h.p.	Fixed blade propeller.	1 × 15,000 K.V.A.	..	150	5	Do.
3 Abitibi Canyan.	237	5 × 66,000 h.p.	Francis vertical.	..	..	150	7	Steel.
4 George Rainer.	215	2 × 29,000 h.p.	Francis vertical.	2 × 23,000 K.V.A.	..	211·8	6	Steel.
5 Earfalls ..	38	2 × 5,000 h.p.	Fixed blade propeller.	2 × 5,000 K.V.A.	..	180	9	Concrete.
		2 × 7,500 h.p.	Kaplan.	2 × 6,000 K.V.A.	..	150	2·5	Do.
6 Barret chute	150	2 × 28,000 h.p.	Francis.	..	..	164	6	Spiral casing steel plate rivetted.
7 Ranney falls.	47	2 × 5,000 h.p.	Francis.	..	..	120	9·8	Spiral concrete casing.

3.10.2: *Station Service and Auxiliaries-Queenston.*—The main service power is supplied by two small water turbine driven generators each rated 2,200 K.V.A. at 2,300 volts. There is already an existing 12 K.V. line connected to an older station at Niagara Falls, passing the screen house at Queenston and supplying the villages of Queenston and the Niagara on the lakeside. By tapping this line and installing a 1,500 K.V.A. 3-phase 12 K.V./2,200 volts transformer in the Power House a dependable standby source of power for all vital station service auxiliaries from another source was provided. It is now possible due to the widespread generating systems of the commission, to have what is commonly called an outside source of service power, except in the very remote and isolated localities.

The most vital service auxiliaries are—

(1) Four governor pumps each with an 125 h.p. motor.

(2) Nine generator fans each driven by a 50 h.p. motor.

(3) Three sump pumps one with 250 h.p. motor and two with a 125 h.p. motor each.

The above are supplied from two of the three service stations since it is imperative to have them in constant operating condition.

At each service station, there is also a bank of transformers stepping down from 2,300 to 550 volts for smaller and less vital equipment, viz., insulationg oil pump filters, battery chargers, compressors, cranes, etc.

Niagara Falls No. 1.—At this plant, there are four sources of service power which are supplied by two transformer banks each of 3 Nos 500 K.V.A. single phase 13·2 K.V./550 volts. It is possible to supply each bank from any of the four generators, the 550 volts side of each bank is connected to a metal clad bus structure with individual feeder O.C.Bs. to the various auxiliaries. By means of a bus tie breaker, all plant service may be supplied from either transformer bank. Main transformer breakers and the bus tie switch are operated electrically from the control room, the other breakers being hand operated.

Niagara Falls No. 2.—Station service for the main plant including the headworks is available from the transformer banks. The first connected to the present No. 1 generator, is called the inside source to differentiate from the second consisting of two single phase 333 K.V.A. units called the outside source, as it is supplied by a 13·2 K.V. power line from St. Catherine about 4 miles distant.

The normal supply is from No. 1 generator and capable of being connected to No. 2 or No. 3 generators when they are installed.

The outside source bank acts as a standby. An automatic and instantaneous scheme of transfer is designed such that if for any reason, the supply from No 1 generator fails, its service tap breaker opens and the breaker of the next running machine is automatically closed, so that a continuous source of power is always available. If there is no generator available, this automatic transfer is made to the outside source oil switch.

At all generating stations, an automatic emergency lighting transfer switch normally supplied from A.C. strategically spaced about the plant, and the control room or outlets which on failure of the A.C. supply, will be automatically lighted by means of the transfer switch connecting them to the D.C. battery. Immediately, the A.C. is restored, the transfer switch makes the reverse change automatically.

D.C. Battery.—The most common voltage rating is 120 V though there are some 250 V. at Queenston, Chatsfalls, Leaside and Burlington. As the average life of a battery is 10 years, it is the usual practice to install one battery for initial operation of the plant and the second in 5 years, so that one good battery is always ready for service.

3.11. *Steam stations.*—The Ontario Hydro-Electric Power Commission have constructed the following steam generating stations to take care of the system peak and low water conditions in hydro stations :—

(1) Richard L. Hearn Generating Station.

(2) J. Clark Keith Generating Station.

These are primarily designed to operate with a low annual station load factor, at peak loads to supply power to the Hydro-Electric Power Commission of Ontario.

3.11.1. *Richard L. Hearn Generating Station.*—This is the largest steam generating station in Canada and is in operation on a 57 acre site of Toronto waterfront. The location of the station is ideal—it is within a short distance of Ontario's largest load centre near economical coal transportation by lake steamer and close to ample quantities of water at low temperature for condensing purposes.

The station will produce 400 M.W. from four units and there is provision for the addition of two more units at a later date, if required, giving the station a six unit capacity of 600 M.W. Initially, the first and third units with a capacity of 88 M.W. each are supplying 25-cycle power to Southern System. Later on, these will be converted for 60-cycle operation. The change to 60-cycle operation will be done by changing the rotor. The second and fourth units each with a capacity of 100 M.W. are operating at 60-cycles. Power generated at 13·8 K.V. is stepped up to 115 K.V. at the station. Each generating unit has its own transformer and individual transmission line capable of carrying 100 M.W.

Power house structure.—The structures are supported on 20 inches compressed concrete piles. They have structural steel frames with brick walls and include the following :—

A main power building with control bay, an intake building enclosing the well, screens and pumps, the coal crusher house and the service building for the coal handling equipment. The main power building houses the steam generators, turbine-generators, and associated equipment. An annexe to the main building contains the offices, laboratory locker rooms, electrical and machine shops.

The modern unit system is used. Each steam generator is connected directly to one turbine-generator, with its condenser and unit feed water heating system and the electric generator is solidly connected to its own transformer.

Each steam generator is an independent operating unit supplying steam to one turbine-generator and receiving feed water from the feed heating system associated with the turbine-generator. There are no cross connecting ties between steam generators in either the steam or the feed heating system. The units have identical and independently complete auxiliary equipment and piping except where for operating flexibility and economy, piping systems are interconnected to avoid unnecessary duplication of standby auxiliary equipment.

The main steam, boiler feed, high and low pressure condensate, extraction heater drip, boiler blow-off, boiler blow down, boiler drain, extraction steam, evaporator equipment, vent and relay, high and low pressure drain and gland steam systems of the four units are not interconnected ahead of the receivers.

The circulating water, bearing and gland cooling water, distilled water, instruments, air, oil generation and chemical feed systems of units 1 and 2 are interconnected, as also the identical feed system units of 3 and 4.

These systems of 1 and 2 units are not interconnected to those units of 3 and 4 except for emergency cross connection in the instrument air system and building service cross connections in the ignition oil system.

However, the chlorine, softened water, service air, and service water systems are interconnected to serve all 4 units.

Purge interlock.—In order to assure that a furnace before firing is purged of combustible gases which might cause an explosion during start-up of a boiler, a purge interlock system is provided for each unit, which requires both an induced draft fan and its assoicated forced draft fan to be operated for a preset and fixed time before an ignition oil torch can be lighted. The purge interlock consists essentially of a differential pressure instrument with timing device, designed to measure differential pressure across the economiser, as a function of the air flow.

When a preset differential pressure corresponding to approximately 60 per cent of the full load air flow is attained, the timer is started to introduce a preset 3 min. delay in closing the ignition power circuit. The differential pressure instrument is adjustable to start the timer at different higher air flows and the timer is adjustable to delay closing of the ignition power circuit a longer or shorter time.

Control interlocks.—To protect operating personnel and equipment in the event of maloperation or failure of equipment, interlocks are provided in the fuel firing equipment control systems to perform the following functions on each boiler :—

(1) Stopping of both induced draft fans will—

(*a*) stop both forced draft fans,

(*b*) close the bunker 'C' oil shut off valve,

(*c*) open the induced draft fan discharge dampers.

(2) Stopping of one induced draft fan will—

(*a*) stop its associated forced draft fan,

(*b*) close the associated induced draft fan discharge damper.

(3) Stopping of both forced draft fans will—

(a) stop the purge interlock cycle,

(b) open the ignition power circuit,

(c) close the bunker 'C' oil shut-off valve,

(d) stop the primary air fans,

(e) open the forced draft fan discharge dampers,

(f) open the hot air recirculation dampers.

(4) Stopping of one forced draft fan will—

(a) close the associated forced draft fan discharge damper,

(b) close the associated hot air re-circulation damper.

(5) Stopping of a primary air fan will stop its associated pulveriser.

(6) Stopping of a pulveriser will stop its associated coal feeder.

(7) Stopping of a pulveriser on overload only will—

(a) stop its associated coal feeder,

(b) stop its associated primary air fan.

Steam generators.—The steam gernerators 120 feet in height are of the radiant water wall type complete with economisers and superheaters. These will have 80,000 feet of seamless steel tubing. Each will be capable of producing 850,000 lb. of steam/hr. at 875 lb. per square inch gauge pressure and 900°F at the superheater outlet with feed water at 365°C and 1 per cent blow down. Each boiler is equipped with superheater, water walls, two regenerative air preheater wind boxes, economiser, and complete boiler setting and refractories and steel casing. Each steam generator is also equipped with 16 burners which are fed from four pulverisers.

The steam generating units designated No. 1 and 2 are also equipped with heavy fuel oil burning equipment consisting of 16 fuel oil burners and associated control equipment.

Soot blowers.—The soot blowers for the steam generators are of two main types. The 1K type blower is for use in high temperature sections where prolonged exposure of uncooled metal to the hot gases would cause damage. This blower is provided with one air motor driven retracting mechanism to remove the blower lance from the hot gas stream when it is not in operation. The other is a non-retractable rotating blower for use in lower temperature areas where continued exposure to the gas stream will not burn up the tubes.

Blowing steam flow rating—

Model 1K blower—100 lb. /min. at 100 lb./sq. inch.

Model $C_1$9B blower—140 lb./blow per unit at 200 lb./sq. inch.

Air heater blower—2,240 lb./hour at 200 lb./sq. inch.

Each blower is provided with an adjustable orifice which reduces steam pressure from 600 lb./sq. inch to the required pressure.

The blowers are all arranged for manual operation. The sequence of blowing a boiler may be selected and each unit started by manual operation of a control valve which starts the air motors operating the units. Each boiler soot blower is provided with a timer which permits the unit to operate on its pre-established cycle and then stop it and shut it off.

Combustion control.—Combustion is controlled by maintaining supply of the proper ratio of fuel and air to the furnace in proportion to the steam demand at the operating pressure.

The combustion control equipment installed for each steam generating unit is pneumatically operated, fully automatic and includes provision for remote manual operation from the boiler guage board and direct manual operation at the final control unit.

For the motors, thermal overload protection is provided and provision is made to keep all motors running through momentary dips in voltage, such as that resulting from an automatic transfer from normal to standby power source. Continued loss of voltage will shutdown the pumps.

Coal pulverisers.—Four pulverisers are provided for each boiler. The equipment has sufficient capacity to meet the following requirements :

850,000 lb. of steam per hour with coal of the analysis specified with 70 hard grade grindability and with one mill out of service.

725,000 lb. of steam per hour with 55 hard grade grindability—10 per cent additional moisture and one mill out of service.

Drive motor—150 h.p. 600 r.p.m.

Air for combustion for each steam generator is supplied by two forced draft fans. Outside air is drawn in, and forced through two regenerative air preheaters, which recover heat from flue gases leaving the economiser section. Part of the air thus preheated is forced through the pulveriser and carries powdered coal to the burners.

The flue gases after giving up heat in the air preheater are drawn through mechanical collectors and electrostatic precipitators by two induced draft fans and return discharged into brick chimneys. The performance of this equipment guarantees the removal of over 95 per cent of soot and fly ash.

Turbines.—The steam turbines take steam at throttle at 850 lb. /sq. inch at 900°F and exhaust at 1·5 inches mercury absolute. They are two cylinders, tandem compound reaction type. The low pressure cylinder has two exhausts both of which are connected to one condenser. The convertible unit turbine will turn at 1,500 rpm. for 25 cycle and 1,800 rpm. for 60-cycle operation. The 60-cycle turbines will run at 1,800 rpm.

The casing of the high pressure cylinder is of cast steel with a cast iron exhaust end. The high pressure rotor is of hollow construction, the body being integral with the extended portion which forms the high pressure end of the shaft. The exhaust end is however a separate forging which is extended to form the other end of the shaft. This method of construction enables the metal forming the body of the rotor to be made of comparable thickness with that of the steel cylinder surrounding it and this obviates difficulties due to differential expansion of rotor and casing when temperature changes occur.

The blading in the high pressure turbine comprises a two-row impulse wheel followed by 29 stages of reaction blading. All the blading material, both impulse and reaction, is of stainless iron containing 12—14 per cent of chromium and has a carbon content of about 0·1 per cent.

A gland of the spring packed labyrinth type is fitted at each end of the high pressure and low pressure turbine.

Main condensers.—The condensers are of the two pass type each containing 60,000 square feet of cooling surface made of 10,000, $\frac{7}{8}$ inch O/D Admiralty metal tubes 26-feet long through which cooling water is pumped.

Cooling water.—One screen house for the screening and chlorination of the water is provided for two main condensers. The water enters the screen house wall through electrically driven and automatically washed travelling screens. After treatment with a minimum amount of chlorine to prevent the formation of slime in the condenser tubes the water is forced through two concrete pressure pipes 54 inches in diameter to serve the main condensers of two units. Booster pumps draw from these lines for other auxiliary cooling and services. Two main condensers discharge into a steel Y section, which connects to a 78″ concrete pipe. This pipe carries the water to the outfall structure at the circulating channel when it returns to the lake.

Feed water heating system.—Each steam turbine is provided with five-extraction connections four of which are used for the present feed water heating system. Treated water is evaporated to make up the unavoidable losses of steam condensate due to blow down, soot blowing, etc.

Control room.—The control room which is in the same level as the main turbine units, is sound proofed, air conditioned, and illuminated by indirect fluorescent lighting.

A semi-circular instrument board 7 feet 6 inches high with a semi-circular bench board in front, directly faces the operator's desk.

From the control room, all high voltage switchgear is remotely controlled and the main units are synchronised and loaded as required.

Coal handling.—Self unloading boats in the ship channel unload directly to the coal storage pile. Bull-dozers and Carry-alls distribute the coal in layers to a height of 35 feet or more.

Coal for use in the station is conveyed from the 300,000-ton stock pile to the powerhouse on a 1,100 feet long conveyor rising to a height of 137 feet and supported on a web like steel structure. This passes the coal through preliminary crushers and transports it to a point over the main coal bunkers where it is distributed by a travelling tipper. Conveying and crushing equipment installed provides for a maximum capacity of 450 tons per hour through the crusher and for a sustained capacity of 350-400 tons per hour. Four steel coal bunkers each of 1,800 tons capacity are installed with coal gates, hoppers, coal scales and required coal chutes. Coal dust collecting equipment is installed in the station above the coal bunkers and in the crusher house. Two independent and complete ash handling systems are installed one for units 1 and 2 and the other for units 3 and 4.

Ash disposal.—Fly ash from the mechanical collectors and electrostatic precipitators is handled pneumatically to a point where it is made into a slurry with the hopper and bottom ash and pumped to the disposal area. There the ash settles and the water is decanted to the circulating channel.

Circulating water pump and screen well houses.—Two circulating water pumps and screen well houses are located at the ship canal. Each house contains equipment to serve ten generating units. Each contain 3 circulating water pumps with travelling screens. Each house contains one screen wash and dewatering pump, three travelling intake screens, three pump wells, trashrack, etc. The first house also contains chlorinating equipment, two motor driven and one engine driven fire water-supply pumps.

Water softening.—Two evaporator feed pumps supply sodium hydrogen Zeolite softened city water to be distilled to the evaporator systems of the 4 units. The evaporator system of the four units are exactly alike and are not interconnected. A 20,000 gallons storage tank is provided from which two evaporator feed pumps, take suction and discharge to the evaporators of units 1 to 4.

Distilled water systems.—There are two separate distilled water systems, one serving units 1 and 2 and a second serving units 3 and 4 for storing distilled make-up water and for supplying this water to the hydraulic systems of the units when it is needed. The systems are not interconnected in any way and are exactly alike.

Chemical feed system.—To scavenge traces of oxygen from the boiler water, a feed of sodium sulphite, an oxygen reducing chemical is introduced by the sulphite feed pumps into the boiler feed water line between the feed water regulating valve and the inlets to the economisers. Approximately 0·1 to 0·2 PPM of sulphite is introduced continuously to the boiler feed water to maintain a residual of 10–20 PPM of the chemical in the boiler water to prevent corrosion of the boiler metal. Caustic soda may also be added with the sulphite feed equipment, if it proves desirable to raise the *p*H at this point.

To prevent the deposition of calcium and magnesium scale forming salts on the internal surface of the boiler drums and tubes, a feed of sodium phosphate is introduced by the phosphate feed pumps into the boiler steam drums below the water level in amounts sufficient to maintain a residual of 30–40 PPM of the chemical in the boiler water. When the chemical is fed in sufficient amounts, with the correct concentration maintained in boiler water, it precipitates any calcium and magnesium (hardness salts) in a form, which does not readily adhere to metal surfaces. Sludge which is formed, is removed from the boilers by blowing them down. Close control of residual phosphates is obtained with the timed cycle intermittent feed system provided for this purpose.

Sampling systems.—Sampling connexions are fitted on equipment and piping so that samples of water and condensed steam may be obtained for chemical and physical tests in order that chemical control may be obtained.

Sampling connexions for testing the following are provided for each unit ;—

(1) Vapour from evaporator.

(2) Water from evaporator condenser.

(3) Feed water from 16th stage deaerating heater.

(4) Condensate from main condenser.

(5) Water from boiler continuous blow down line before control line.

(6) Water from evaporator continuous blow down line before control valve.

(7) Effluent from softened water degassifier.

(8) Effluent from evaporator preheater.

(9) Steam from boiler steam drum after scrubber.

(10) Water from boiler feed line after sulphite feed connexion.

(1) Samples taken from the cooler are tested for total solid silica, CO_2 contents and *p*H value.

(2) A condensate sample is drained continuously from the evaporator condenser and piped through a sample cooler to a conductivity cell. Conductivity of the sample is recorded by pen No. 2 on conductivity recorder mounted on the turbine gauge board. Alarm contacts on the conductivity recorder close when conductivity increases to four micromhos to give an alarm on the turbine gauge board annunciator of high conductivity indicating excessive carry over of solids from the evaporator.

(3) A sample of heated and deaerated feed water is withdrawn from the outlet of the 16th stage heater and piped to a sample cooler for the purpose of testing the feed water for dissolved O_2 and pH.

(4) Conductivity of the condensate leaving the condenser is recorded by pen No. 1 on conductivity recorder mounted on the turbine gauge board. Alarm contacts on the conductivity recorder close when conductivity increases to two micromhos to give an alarm on the turbine guage board annunciator of high conductivity indicating leakage of circulating water into the shell side of the condenser.

(5) A sample of boiler continuous blow down is withdrawn from the continuous blow down line ahead of the blow down control valves and piped to a sample cooler for the purpose of testing to determine the solids concentration, alkalinity, phosphates, sulphite, silica and pH of the boiler water.

(6) A sample of evaporator water is withdrawn continuously from the evaporator continuous blow down line ahead of the blow-down control valve and piped through a sample cooler to a conductivity cell. Conductivity of the sample is recorded by pen No. 3, on conductivity recorder mounted on the turbine gauge board. Alarm contacts on the conductivity recorder close when conductivity increases to 7, micromhos to give an alarm on the turbine gauge board annunciator of high conductivity indicating the maximum limit of total dissolved solids.

(7) From the drain of the degassifier for each set of softeners a sample of sodium hydrogen Zeolite softened and degassified city water is withdrawn and piped down to pH cell. The pH of the sample is recorded on pH recorder indicating the correct blending of the effluents at the sodium hydrogen Zeolite exchangers.

(8) Sample of heated and deaerated water is withdrawn from the evaporator preheater and piped to a sample cooler for testing for dissolved oxygen and carbon-di-oxide in the feed to the evaporator.

(9) A steam sample is extracted from the steam drum of the boilers. A portable conductivity bridge is provided for determining the conductivity of the liquid samples from the degassing condenser to indicate steam purity.

(10) A sample of feed water is extracted from the feed water line down stream from the sulphite feed connection and piped to a sample cooler for testing to check the amount of sulphate fed to the boiler.

Oxygen recording equipment.—This automatically takes a sample of the flue gas from the boiler outlet, makes an analysis and records the oxygen content on a chart.

Smoke density recording equipment.—This is provided for each boiler and it automatically determines and records the density of smoke in the flue gas from the furnace as it enters the inlet to the induced draft tube.

3.11.2. *J. Clark Keith Steam Generating Station at Windsor.*—The Commission's second largest steam station is located on a 120 acre site on the Detroit River on the southern limits of the City of Windsor. There is an abundant supply of cooling water, adequate area for the storage of coal and disposal of fly ash. The generators are 66 M.W. capacity and power is generated at 13·8 K.V. 60 cycles.

This station will have an ultimate capacity of 264 M.W. with four units.

Power-house structure.—The main structures are of reinforced concrete frame with walls of brick supported on 12 inches steel H-piling driven to rock. They include a main power house building housing the steam generators, turbine-generators and administrative offices, a control building, two service buildings, a screen house, the crusher house and the coal dock.

Following the modern unit arrangement, each unit is complete in itself. Each steam generator is connected directly to one turbine-generator with condenser and unit feed water heating system. The electric generator is solidly tied to its own transformer bank.

Steam generators.—The steam generators are of the radiant water wall type complete with economiser and superheaters. They will produce 650,000 lb/hr. steam at 875 lb/sq. in. at 900°F at the superheater outlet with feed water at 418°F and 1 per cent blow down. Each steam generator is equipped with twelve coal burners into which pulverised coal is fed from four pulverisers. Air for combustion is supplied by two forced draft fans through two regenerative air pre-heaters. Heat of the flue gases leaving the economiser section of the steam generator is transferred to the air. Part of the pre-heated air, when forced through the pulveriser carries powdered coal to the burners.

The flue gases after giving up heat to the air pre-heaters, are drawn by two induced draft fans, through mechanical collectors and electrostatic precipitators, located on the roof. The gases are then discharged to steel stacks lined with gunnite. The performance of the equipment guarantees the removal of over 95 per cent of the soft and fly ash in the gases.

Steam turbines.—The steam turbines receive steam at the throttle at 850 lb. per square inch at a temperature of 900°F and exhaust at 1·5 inches mercury absolute. The turbines are two cylinder, impulse type. The low pressure cylinder has two exhausts which are connected to twin condensers.

Each of the twin condensers has 13,750 square feet of cooling surface made up of $\frac{7}{8}$ inch outer diameter admirality metal tubes 21 feet 9 inches long through which cooling water is pumped from the intake terminal under the Power house basement. The condensers are single pass, and the cooling water discharges to the outlet terminal which is also under the basement floor.

Cooling water.—Cooling water for the condensers enters the screen house well from the Detroit river. There, debris is removed by electrically driven and automatically washed travelling screens. The raw water is treated with a minimum amount of chlorine to prevent the formation of slime in condenser tubes. It is discharged through tunnels under the power house basement at a point down stream from the intake.

Steam withdrawn from the turbine at five extraction points is used for heating the condensate being returned to the steam generator. Condensate pumps draw the condensate from the hot well of the condenser and force it through two low pressure heaters into the deaerator. From the deaerator, the feed pumps force the feed water through two high pressure heaters into the economiser section of the steam generator. Certain unavoidable losses of steam and condensate, for example due to blow down, are replaced by evaporating the treated water. The vapour joins the main stream of feed water in the deaerator.

Control.—The control room is adjacent to the high voltage switch gear and main transformers. From this point all high voltage switchgear is remotely controlled and the main units are synchronised and loaded as required.

All auxiliaries are motor-driven, being supplied either from a unit transformer or from an outside source.

Coal handling.—At the coal dock on the Detroit river self unloading boats discharge into a large hopper. A belt conveyor carries the coal from the dock to a second belt conveyor which by means of a swinging boom, deposits the coal on the ground in a crescent

shaped pile. From here, Bull-dozers and Carry-alls move the coal either to the storage or to a reclaiming hopper. From the reclaiming hopper, the coal is carried by another belt conveyor to the crusher house where it is reduced below $\frac{3}{4}$ inch size. After passing through the crusher, it is carried by a fourth belt conveyor to the coal bunkers and distributed by a travelling tipper.

Ash disposal.—Fly ash from the mechanical collectors and electrostatic precipitators is carried pneumatically to a tank. It is made into a slurry with the hopper and bottom ash and then pumped to the disposal area where the ash settles and water is decanted to the river.

3.12. *Load Dispatching.*—All operating Engineering such as load allocation between plants, efficient loading of plants, transmission lines load scheduling, etc., is conducted by the Load Dispatching Department.

The Southern California Power Company operates 70 Supervisory Controlled Transformer and distributing Stations, 8 to 11 of them being under control of the single sub-station. Originally the Company had a great many one man-semi-attended stations and was under pressure from the Union to make them fully attended. It was decided to do away with the attendance altogether and try supervisory control which has given good satisfaction over the years. These stations are visited regularly by travelling operators each of whom may look after as many as 15 unattended and automatic supervisory controlled stations. The maximum time required to get maintenance men out in time of trouble would be about 2 hours. Equipment used for control has been supplied by three manufacturers, Control Corporation, G.E. and Westinghouse. No auto-reclosing breakers are used. Oscillographs are used extensively and relay indications are automatically annunciated at the controlling station. Mimic busses were not used originally on the controlling switch boards but this was found to be a serious oversight, and have been provided for newer installations. There have been several operating errors which were believed to have resulted from the lack of the mimic bus.

3.13. *Centralized Load Control and System Operation—Georgian Bay System.*—The following defines the duties and responsibilities of the Georgian Bay System load supervisors and the operating staff of the system in matters relating to centralized load control and system operation.

The Part I covers the normal functions and Part II the modified functions when communication is lacking or when because of simultaneous troubles at separate points it would be undesirable to delay action.

PART I.

Normal Functions.

The load supervisor shall exercise supervisory control over all generators, trunk lines and the lines of the Georgian Bay System.

He shall—

(1) Be responsible for the delivery of an adequate amount of power to the system and for the efficient allocation of load among the various plants.

(2) Direct, what load each station shall carry, together with the amount of generator capacity which shall be kept connected to the bus, and under special circumstances when generators of different efficiencies are involved, specify the units which shall be used.

(3) In matters relating to service security have control over the outages of apparatus for work thereon.

(4) Exercise operational control over apparatus in accordance with instructions which cover the system operation of the various districts of the eastern division to be developed by the District Superintendent and Chief Operators.

(5) Designate the load which must be dropped in case of emergency to safeguard apparatus or because of inadequate capacity.

The plant Chief Operators are responsible for—

(i) Safeguarding the apparatus against possible injury through overloads, or other causes and they may impose any restriction on the use of such apparatus, which they deem necessary under the circumstances. They shall, however, at the earliest possible moment inform the load supervisor of any such restrictions.

(ii) The efficient allocation of load among the generators within the plant or plants over which they exercise operating control. All work of programme involving the outage of any apparatus affecting system capacity shall be submitted to the load supervisor, preferably the chief load supervisor, as far in advance as practicable. The load supervisor shall carefully review them in order to determine whether—

(1) The necessary outages can be permitted safely without interfering with system capacity;

(2) All foremen who might have to work on the apparatus, have been consulted.

(3) There is any confliction or overlapping in requests from the various sources.

If the load supervisor finds objection to the programme submitted he shall refer them back to the proper parties with suggestions for appropriate adjustments to suit the conditions. If he finds no objection, he shall approve them and furnish every station concerned with a statement showing the work to be done, making the necessary arrangements for apparatus outage, service interruption, etc., which will affect system capacity.

3.14. *Maintenance Practice*—(1) *Trash Racks.*—While it is necessary at certain times of the year to give the cleaning of trash racks constant attention, the practice of cleaning the debris from the racks at least once every week at all times shall be followed.

(2) *Head gates.*—Head gate operating mechanism, shall be tested at least once each month to make certain that they are in satisfactory working order. The gates themselves shall be examined at least every 6 months or repaired, if necessary.

(3) *Penstocks.*—All penstocks shall be given a thorough inspection at least once every year.

(4) *Large Hydraulic valves.*—These shall be operated at least once each month and kept well oiled and greased so that they will operate satisfactorily at all times.

(5) *Turbines.*—All turbines which can be unwatered by means of hydraulic valves shall be inspected at least once in every 3 months. Turbines which can only be unwatered by the handling of stop logs, shall be inspected at least once a year. During these inspections, all gates, gate bolts, links, pins, etc., should be carefully examined. The bearings shall be adjusted and the general appearance of the turbine carefully noted.

(6) *Governors.*—In order to keep governors in proper working order constant care and supervision are required. In addition to this, a complete examination and test shall be made of each governor at least once each year.

Maintenance of wire ropes.—Wire ropes used on head works installations, etc., where they operate part time under water deteriorate more rapidly through corrosion.

Various schemes to prevent corrosion have been tried, including galvanizing of the cable strands and the use of grease and oil lubricants.

A method of applying zinc coating to cable strands has been developed more recently, where the wires are coated before drawing.

Conclusions reached up to the present time, are that best results are obtained by treating both galvanized and plain wire rope with a reliable inter-strand lubricant and a suitable but adhesive, outer coating. Leadolène, a product of the Brook Oil Company appears to have the desired characteristics for this purpose as indicated by the Commission's experience and also by that of the Dominion Government following its use on canal installations.

Wire rope for under water service shall in general be of galvanized construction.

The lubrication of wire rope involved in under water service shall be governed by the following :—

New Rope.—New cable shall be cut into desired lengths, if possible and formed into coils with the turns fitting not too closely together.

A quantity of Leadolene No. 350 sufficient to cover a coil of cable shall be placed in an appropriate metal container. By means of suitable heaters, the Leadolene shall be brought to a temperature of about 200°F and held there at during the processing period.

The coil of the cable shall be immersed for not less than one hour in the hot Leadolene after which it shall be allowed to drip in varied positions until cool to ensure an even distribution of the lubricant.

For a sealing coat, Leadolene No. 450 shall be applied by hand at room temperature using say an old glove and working the material well into the cable and filling up the valleys.

Subsequent treatment.—The treatment with No. 450 Leadolene outlined above at room temperature shall be repeated annually while the cable is in place or more often if necessary particularly where the cables are normally submerged.

Treatment for used or partially corroded rope.—The cable shall be coiled rather loosely and immersed for at least one hour in transformer oil at a temperature of from 150° to 180° F after which the corrosion should be thoroughly brushed off.

This should be followed by the complete treatment as for new rope.

Treatment at room temperature is recommended for crane cables, slings, etc. Leadolene No. 400 is an excellent lubricant for open gears, studing surfaces, etc.

3.15. *Cables*—(i) *P.V.C. Cables.*—Thermoplastic insulation for wire, particularly P.V.C. has been in use in the Ontario Hydro Commission for more than ten years. During this time changes in compounding and processing have so improved the material that it has become one of the most widely used for insulation. Nevertheless like most thermoplastics, P.V.C. has certain limitations.

The maximum continuous temperature to which P.V.C. may be exposed in service is 60°C (140°F) this being the maximum temperature of the conductor. The excessive overheating of P.V.C. can cause it to flow and rag away from the conductor and even weld to neighbouring insulation. It is highly advisable therefore to select the conductor size and keep the loading so that the 60°C limit is not exceeded.

(ii) 110 *KV Gas Filled Cable.*—A 110 KV gas filled cable forms a link in the 110 KV 60 cycle circuit between Richard L. Hearn G. S. and Toronto Strachan Transformer Station.

The line is composed of 3 single core 1,000 MCM lead covered cables encased in a steel pipe. The pipe is filled with nitrogen gas at a pressure of approximately 200 lb./square inch. The cable terminates in oil filled bushings. Pressure guages and oil level indicators have been installed at each termination in order to observe any severe changes. At Esplanade T.S. an alarm guage has been installed in the gas intake box to sound a claxon at a low pressure of 175 lb./square inch or at a high pressure of 245 lb./square inch.

Any leakage in the pipe line will be evident by a drop in pressure shown on the guage. The oil in the bushings will vary with temperature changes. The variation in oil volume is taken care of by a compensator tank mounted on the cover holding the bushing. This compensator functions in much the same manner as an oil reservoir tank with the exception that it is also under a pressure of 200 lb./square inch of Nitrogen gas.

4. Tennessee Valley Authority.

4.1 *General.*—Sketches PS 28 and PS 29 give the location and other details of power stations in the Tennessee River in its 650 mile stretch from the mouth.

The following table gives facts about major T.V.A. Dams.

TABLE 4.

FACTS ABOUT MAJOR T.V.A. DAMS.

Main River Projects.	River.	State.	County.	Nearby City.	Type of Dam.	Maximum Height (Feet) (a)	Length (feet).	Drainage area above dam (square miles).	Length of Lake (miles).	Maximum width of lake (miles).	Area of Lake (acres). (e)	Shore line (miles). (e)	Ordinary Minimum Elevation (feet above sea level).	Maximum Controlled Elevation (feet above sea level).	Full Pool Elevation (feet above sea level).	Volume at Ordinary Minimum Elevation (acres-feet).	Volume at Maximum Controlled Elevation (acres-feet).	Useful controlled Storage (f) (acres-feet).	Construction started.	Closure.	Construction Completed (1st unit on line).	Cost (g) (actual or estimated). ($)	Concrete cubic yards.	Earth and/ or Rock Fill (cubic yards).	Generating Capacity Present and Scheduled KW and number of Units ( ).	Additional future capacity KW and number of Unit ( ).	Lock size (feet).	Lock Maximum Lift (feet).	Main River Projects.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)
Kentucky ..	Tenn. ..	Ky. ..	Marshall (b) Livingston.	Paducah ..	Concrete gravity (j)	206	8,422	40,200	184·3	2·5	158,300	2,380	354	375	359	1,991,800	6,002,600	4,010,800	7– 1–38	8–30–44	9–14–44	16,200,000	1,356,100	5,582,000	160,000 (5)	..	110×600	73	Kentucky.
Pickwick landing	Tenn. ..	Tenn. ..	Hardin ..	Savannah ..	Do. (j)	113	7,715	32,820	52·7	1·5	42,800	496	408	418	414	673,000	1,091,400	418,400	3– 8–35	2– 8–38	6–29–38	43,500,000	630,300	3,081,000	216,000 (6)	..	110×600	63	Pickwick.
Wilson ..	Tenn. ..	Ala. ..	Lauderdale (b) Colbert.	Sheffield Florence.	Do.	137	4,862	30,750	15·5	1·6	15,800	154	504·5	507·88	507·5	510,000	562,500	52,500	4–14–18	4–14–24	9–12–25	48,800,000	1,259,400	0	436,000 (18)	—	60×300 60×292	90 (k)	Wilson.
Wheeler ..	Tenn. ..	Ala. ..	Lauderdale (b) Lawrence.	Town Creek ..	Do.	72	6,342	29,590	74·1	2·8	67,100	1,063	550	556·28	556	802,900	1,150,400	347,500	11–21–33	10– 3–36	11– 9–36	46,000,000	747,300	0	259,200 (8)	..	60×360	52	Wheeler.
Guntersville	Tenn. ..	Ala. ..	Marshall ..	Guntersville ..	Do. (j)	94	3,979	24,450	82·1	2·5	69,100	962	593	595·44	595	855,800	1,018,700	162,900	12– 4–35	1–16–39	8– 1–39	36,100,000	289,700	813,900	97,200 (4)	—	60×360	45	Guntersville.
Hales Bar ..	Tenn. ..	Tenn. ..	Marion ..	Chattanooga ..	Do. (j)	112	2,315	21,790	39·9	1·1	6,700	162	632	635	635	135,300	154,200	18,900	10–18–05	..	11–13–13	32,900,000	—	—	99,700 (16)	..	60×265	41	Hales Bar.
Chickamauga	Tenn. ..	Tenn. ..	Hamilton ..	Chattanooga ..	Do. (j)	129	5,800	20,790	58·9	1·7	34,500	810	675	685·44	682·5	375,900	705,300	329,400	1–13–36	1–15–40	3– 4–40	38,900,000	491,800	2,635,800	108,000 (4)	..	60×360	55	Chickamauga.
Watts Bar ..	Tenn. ..	Tenn. ..	Meigs (b) Rhea.	Spring City ..	Do. (j)	112	2,960	17,310	72·4	1·3	38,600	783	735	745	741	754,400	1,132,000	377,600	7– 1–39	1– 1–42	2–11–42	33,800,000	480,200	1,173,000	150,000 (5)	..	60×360	70	Watts Bar.
Fort Loudoun.	Tenn. ..	Tenn. ..	Loudon ..	Lenoir City ..	Do. (j)	122	4,190	9,550	55·0	0·7	14,500	360	807	815	813	277,200	386,500	109,300	7– 8–40	8– 2–43	11– 9–43	41,000,000	575,000	3,594,000	128,000 (4)	..	60×360	80	Fort Loudoun.
Tributary Projects.																													*Tributary Projects.*
Apalachia ..	Hiwassee ..	N.C. ..	Cherokee (c) ..	Farner ..	Concrete gravity ..	150	1,308	1,018	9·8	0·3	1,123	31	1,240	1,280	1,280	22,840	58,570	35,730	7–17–41	2–14–43	9–22–43	22,300,000	448,500	0	75,000 (2)	..	..	..	Apalachia.
Hiwassee ..	Hiwassee ..	N.C. ..	Cherokee ..	Murphy ..	Do. ..	307	1,287	968	22	0·6	6,240	180	1,415	1,526·5	1,526	73,300	438,000	364,700	7–15–36	2– 8–40	5–21–40	19,900,000	793,000	14,200	57,600 (1)	57,600 (1)	..	..	Hiwassee.
Chatuge ..	Hiwassee ..	N.C. ..	Clay	Hayesville ..	Earth Fill ..	144	2,850	189	13	1·0	7,150	132	1,860	1,928	1,928	18,500	247,800	229,300	7–17–41	2–12–42	..	7,100,000	21,900	2,347,400	—	8,000 (1)	—	—	Chatuge.
Ocoee No. 1	Ocoee ..	Tenn. ..	Polk	Benton ..	Concrete gravity ..	135	840	595	7	—	1,900	18	816·9	837·65	837·65	58,200	91,300	33,100	8– –10	12–15–11	1–10–12	2,400,000	160,000	0	18,000 (5)	..	..	..	Ocoee No. 1.
Ocoee No. 2.	Ocoee ..	Tenn. ..	Polk	Benton ..	Rock Filled Timber.	30	450	516	..	..	..	..	..	..	..	..	..	..	5– –12	..	10– –13	2,300,000	0	0	19,900 (2)	..	..	..	Ocoee No. 2.
Ocoee No. 3.	Ocoee ..	Tenn. ..	Polk	Ducktown ..	Concrete gravity ..	110	612	496	7	0·3	606	24	1,413	1,435	1,435	4,240	11,670	7,430	7–17–41	8–15–42	4–30–43	8,100,000	111,000	82,000	27,000 (1)	..	..	—	Ocoee No. 3.
Blue Ridge ..	Toccoa ..	Ga. ..	Fannin ..	Blue Ridge ..	Earth Fill ..	167	1,000	232	10	..	3,330	60	1,590	1,691	1,690	14,500	200,800	186,300	11– –25 (h)	12– 6–30	7– –31	4,900,000	..	1,500,000	20,000 (1)	..	..	—	Blue Ridge.
Nottely ..	Nottely ..	Ga. ..	Union	Blairsville ..	Earth and Rock Fill.	184	2,300	214	20	1·1	4,290	106	1,640	1,780	1,780	0	184,400	184,400	7–17–41	1–24–42	..	5,400,000	17,700	1,552,300	..	10,000 (1)	..	..	Nottely.
Norris ..	Clinch ..	Tenn. ..	Anderson (b) Campbell.	Knoxville ..	Concrete gravity (j)	265	1,860	2,912	72-56 (d)	1·2	34,200	800	930	1,034	1,020	286,000	2,567,000	2,281,000	10– 1–33	3– 4–36	7–28–36	30,200,000	1,002,300	181,700	100,800 (2)	..	..	—	Norris.
Fontana ..	Little Tenn.	N.C. ..	Graham (b) Swain.	Robbinsville ..	Concrete gravity ..	480	2,365	1,571	29	0·6	10,670	248	1,525	1,710	1,710	287,000	1,444,300	1,157,300	1– 1–42	11– 7–44	1–20–45	73,300,000	2,813,000	760,000	202,500 (3)	..	..	—	Fontana.
Douglas ..	French Broad.	Tenn. ..	Sevier	Sevierville ..	Concrete gravity (j)	202	1,705	4,541	43·1	1·5	31,600	555	920	1,002	1,002	94,400	1,514,100	1,419,700	2– 2–42	2–19–43	3–21–43	44,700,000	548,200	622,800	112,000 (4)	..	..	..	Douglas.
Cherokee ..	Holston ..	Tenn. ..	Jefferson (b) Grainger.	Jefferson City ..	Do. (j)	175	6,760	3,429	59	1·5	31,100	463	980	1,075	1,075	92,300	1,565,400	1,473,100	8– 1–40	12– 5–41	4–16–42	32,600,000	686,300	3,156,925	120,000 (4)	..	..	..	Cherokee.
Fort Patrick Henry.	S. Fork Holston.	Tenn. ..	Sullivan ..	Kingsport ..	Concrete gravity ..	95	670	1,903	10·4	0·25	980	30	1,258	1,263	1,263	25,200	29,850	4,600	July 1951.	..	..	14,000,000	66,000	0	36,000 (2)	—	..	—	Fort Patrick Henry.
Boone ..	S. Fork Holston.	Tenn. ..	Sullivan (b) Washington.	Johnson City Kingsport.	Concrete gravity (j)	140	1,330	1,840	16–15 (l)	0·5	4,880	125	1,330	1,385	1,385	47,500	211,000	163,500	8–29–50	..	..	24,100,000	191,000	530,000	75,000 (3)	..	..	..	Boone.
South Holston.	S. Fork Holston.	Tenn. ..	Sullivan ..	Bistol, Va.-Tenn.	Earth and Rock Fill.	285	1,600	703	24·3	1·3	7,580	168	1,616	1,742	1,729	118,800 (k)	744,000 (k)	625,200	8– 4–47 (i)	11–20–50	2–13–51	31,800,000	88,350	5,943,000	35,000 (1)	..	..	..	South Holston.
Watauga ..	Watauga ..	Tenn. ..	Carter	Elizabethton ..	Do. ..	318	900	468	17	0·8	6,430	106	1,815	1,975	1,959	51,600	678,800	627,200	7–22–46 (i)	12 –1–48	8–30–49	31,650,000	67,400	3,534,500	50,000 (2)	..	..	—	Watauga.
Great Falls ..	Caney Fork.	Tenn. ..	Warren White.	Rock Island ..	Concrete gravity ..	92	800	1,675	22	—	2,270	120	762	804·9	804·9	5,100	54,500	49,400	–15	12– 8–16	–16	4,500,000	..	..	31,860 (2)	..	..	..	Great Falls.
										Total ..	601,749	10,336				7,575,780	22,245,090	14,669,260							2,634,760	75,600			

NOTE.—Total T.V.A. capacity installed and scheduled, including fuel plants (3,144,050 KW) and minor hydro plants (22,140 kw) is 5,800,950 kw. Generating units installed in the remaining vacant hydro stalls (75,600 KW) will increase T.V.A.'s capacity to 5,876,550 KW. Present installations and currently planned additions of the Aluminum Company (366,790 kw) and the U.S. Engineer Projects on the Cumberland (595,000 KW) will bring the total T.V.A. operated system to 6,838,340 KW. This total does not include U.S. Engineer projects on the Cumberland (286,800 KW) tentatively scheduled after February 1, 1955.

(a) Foundation to roadway or deck.
(b) River is county line.
(c) Powerhouse is in Polk County, Tennessee.
(d) Seventy-two miles on the Clinch River; 56 miles on the Powell River.
(e) Full pool elevation.

(f) Useful controlled storage is the volume between the ordinary minimum elevation and maximum controlled elevation.

(g) This column does not include the future units at Hiwassee, Chatuge and Nottely nor generating plant substations.

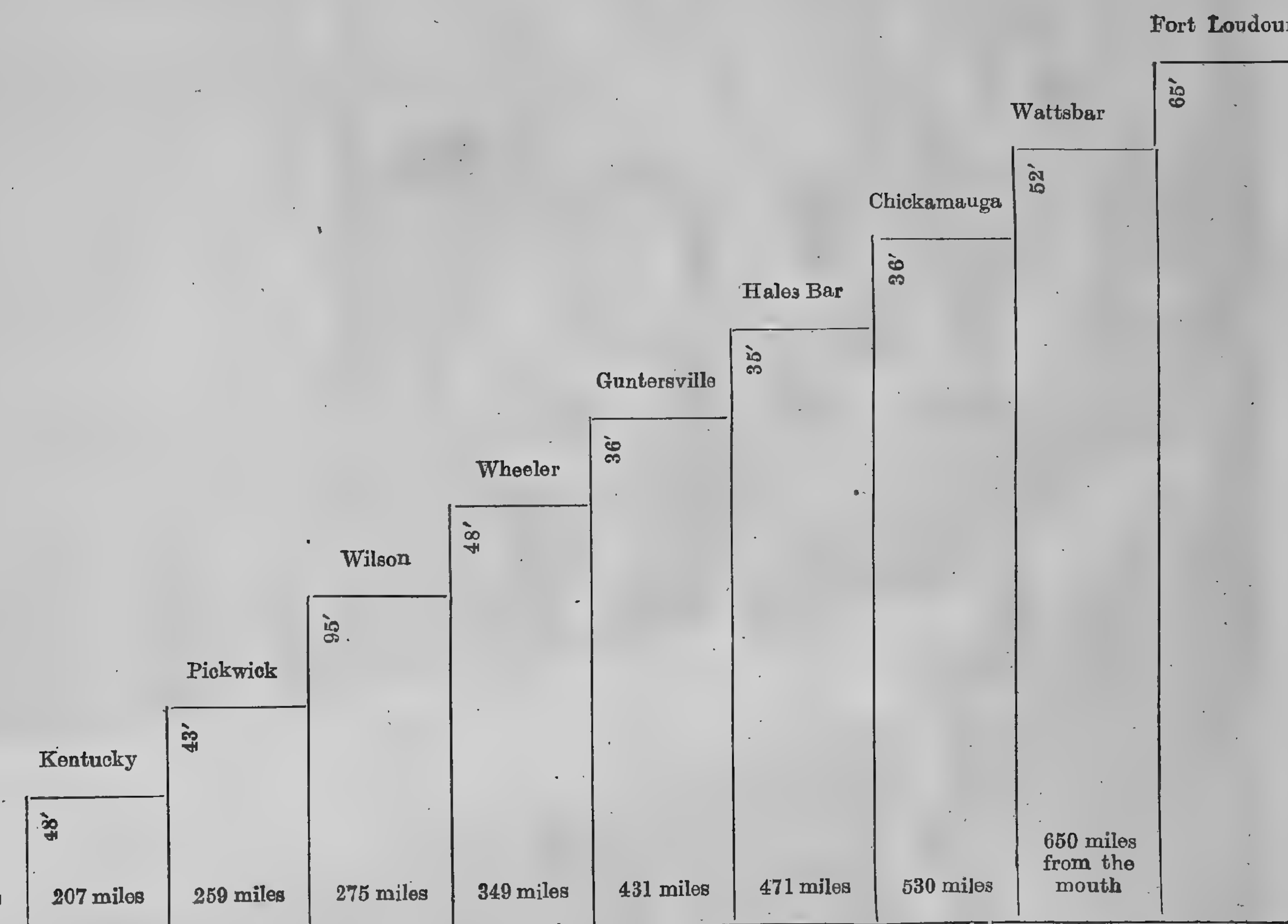
(h) Construction discontinued early in 1926; resumed in March 1929.

(i) Initial construction started February 1942; temporarily discontinued to conserve critical materials during war.

(j) With earth embankments.

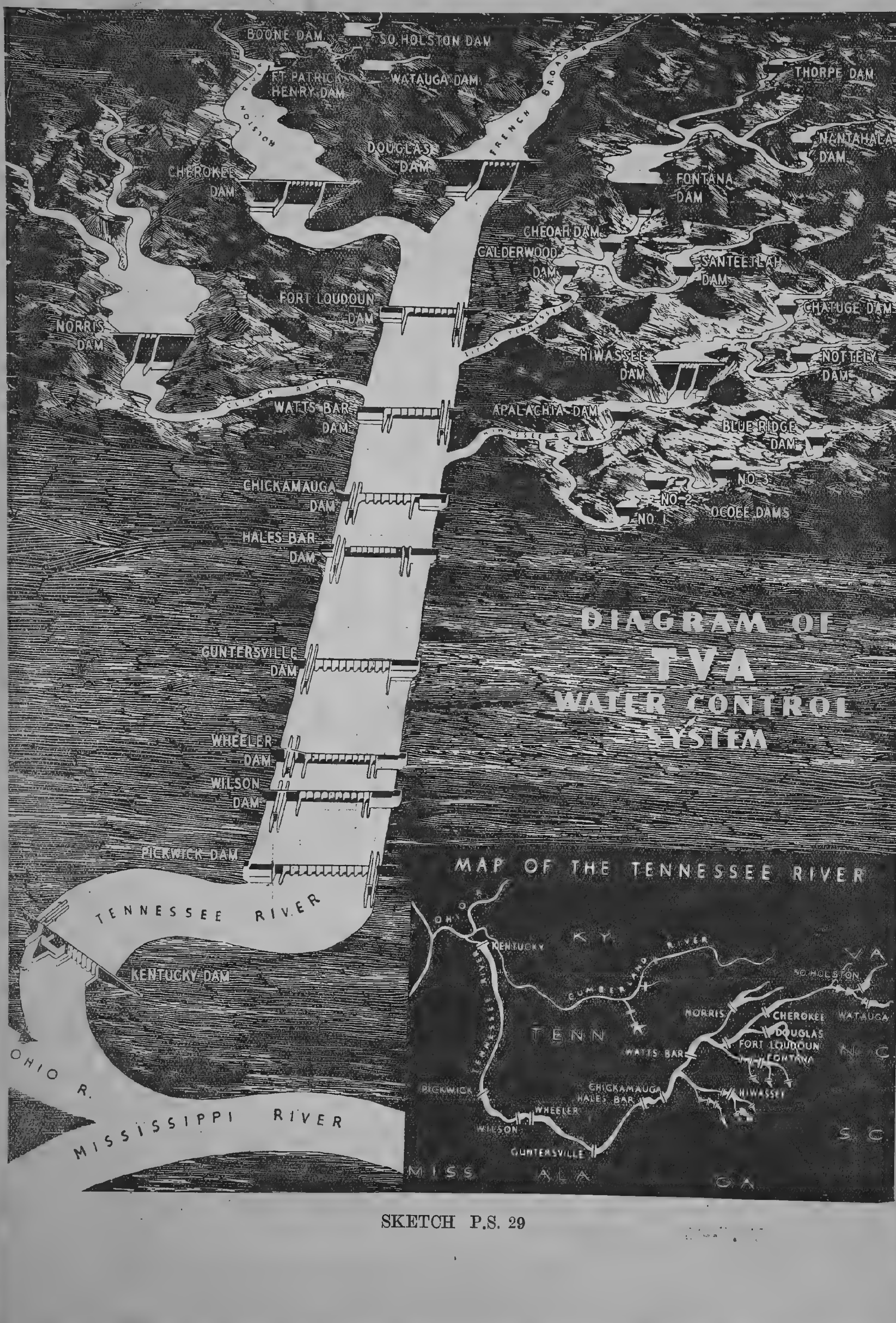
(k) Two lifts.

(l) Sixteen miles on the South Fork Holston River; 15 miles on the Watauga River.



		Kentucky	Pickwick	Wilson	Wheeler	Guntersville	Hales Bar	Chickamauga	Wattsbar	Fort Loudoun
Distance from the mouth of the river ..	23 miles	207 miles	259 miles	275 miles	349 miles	431 miles	471 miles	530 miles	650 miles from the mouth	
Year of operation		1944/1948	1938/1942	1925/1943	1936/1941	1939	1913/1916	1940	1942	1943/1944
Height of dam		206′	113′	137′	72′	94′	112	129′	112′	122′
Length		8,422′	7,715′	4,862′	6,342′	3,979′	2,315	5,800′	2,960′	4,190′
Discharge		65,000 Cusecs	54,000 Cusecs	59,500 Cusecs	49,000 Cusecs	42,000 Cusecs	38,000 Cusecs	36,500 Cusecs	26,400 Cusecs	13,800 Cusecs
Installed capacity KW.		5×31,500	6×36,000	18×25,200	8×32,400	4×24,300	14 sets 3700 to 3400 KW.	4×27,000	5×30,000	4×32,000

SKETCH P.S. 28


BOONE DAM
SO. HOLSTON DAM
FT. PATRICK HENRY DAM
WATAUGA DAM
THORPE DAM
HOLSTON
FRENCH BROAD R.
DOUGLAS DAM
NANTAHALA DAM
CHEROKEE DAM
FONTANA DAM
CHEOAH DAM
CALDERWOOD DAM
SANTEETLAH DAM
FORT LOUDOUN DAM
CHATUGE DAM
NORRIS DAM
LITTLE TENNESSEE
HIWASSEE DAM
NOTTELY DAM
CLINCH RIVER
WATTS BAR DAM
APALACHIA DAM
HIWASSEE R.
BLUE RIDGE DAM
NO. 3
NO. 2
NO. 1
OCOEE DAMS
CHICKAMAUGA DAM
HALES BAR DAM
DIAGRAM OF TVA WATER CONTROL SYSTEM
GUNTERSVILLE DAM
WHEELER DAM
WILSON DAM
PICKWICK DAM
TENNESSEE RIVER
KENTUCKY DAM
OHIO R.
MISSISSIPPI RIVER
MAP OF THE TENNESSEE RIVER
OHIO
KENTUCKY
KY.
CUMBERLAND RIVER
VA.
SO. HOLSTON
TENNESSEE RIVER
NORRIS
CHEROKEE
WATAUGA
TENN.
DOUGLAS
FORT LOUDOUN
FONTANA
WATTS BAR
N. C.
PICKWICK
CHICKAMAUGA
HALES BAR
HIWASSEE
WHEELER
WILSON
GUNTERSVILLE
S. C.
MISS.
ALA.
GA.

SKETCH P.S. 29

4·2. *Types of Plants.*—Waterways for the delivery of water to Generating Stations fall under three types—

(1) Main river type with a low dam and with the power-house built into the dam and usually with a navigation lock.

(2) Tributary type with a high dam and with the power-house close to its base.

(3) Diversion type, with a small diversion dam and a tunnel leading to a remote power-house.

The main river type includes Wheeler, Pickwick, Guntersville, Chickamauga, Watts Bar, Fort Loudoun, Kentucky and Halesbar, all located on the main river. The river at most of these sites is comparatively wide and shallow. The structures include earth embankments, gravity type concrete dams, broad spillways, short intakes to several generating units and navigation locks. The rated heads range from 35 to 65 feet and propeller type low-speed turbines are used. The power-house in each case is built into the toe of the dam as part of the dam structure.

The tributary type includes Norris, Hiwassee, Cherokee, Douglas, Fontana and Boone all on tributaries and also the Wilson Project, which although on the main river fits into this classification by virtue of its relatively high head. The river at each of these sites is narrow (except at Wilson) and the banks are steep. The structures include concrete type gravity dams—some with earth embankments—spillways, longer intakes and except at Wilson, there are fewer generating units than at the main river plants. Rated heads range from 90 to 350 feet and Francis type medium speed turbines are used The power-house in these cases is built close to the toe of the dam, but was not made a part of the dam as was the case with most of the main river dams.

The diversion type includes Ocoee 3, Apalachia, Watauga and South Holston. The terrain was rough and the river was narrow. The structure in each case includes a dam, tunnel or power conduit, a surge tank and penstocks. Rated heads range from 180 to 360 feet and Francis type medium-speed turbines are used. The power-house is separated from the dam, by a distance ranging from a few feet to several miles.

While these three distinct types of development have been needed to meet the natural conditions at the various sites, a considerable amount of similarity has been achieved between stations of the same type. In the case of Douglas, the site happened to be similar to Cherokee and both the stations are similar. Guntersville and Chickamauga are designed with several identical features.

The main river plants are operated continuously to utilise all the available stream flow and the tributary plants are operated to meet stream flow conditions and system transmission requirements.

Of the main river plants, all except two have been built by the T.V.A. Of these two, the Hales Bar hydro-plant constructed about 35 years ago is the older. When this plant was built, low head turbines of large size were not available, and it was necessary to mount three water wheels on a single shaft to obtain an output of 3,500 KW at the rated head of 36 feet. Because of this capacity limitation, it was necessary to install 14 units to obtain a capacity of 50,000 KW.

The Wilson plant is the largest hydro-plant of the system with a capacity of 352,200 KW. There are 14 units at this plant including six which have been installed by the T.V.A.

Trash Racks.—The main river projects are provided with vertical trash racks either placed in the emergency gate slot or at the face of the intake structure. In the latter case, the racks are secured in embedded steel shapes which also serve for the

retention of stop logs if a dewatering operation has to be effected for the maintenance of the gates or the slots. The racks are designed for a differential head of about 5 feet and an average velocity through the net area of the racks of about 3·5 feet per second. The allowable stresses are on the basis of 18,000 lb. per sq. inch intensity.

The tributary plants, including 9 built by the Authority and 6 acquired properties, are operated on an annual cycle, which provides for filling the reservoirs during the spring, and releasing the water during the summer and fall. During the filling season, the generating equipment is operated only to the extent necessary to maintain voltage or to fill out the capacity requirements during peakload periods when power from other sources is not adequate.

In the short in take class, passage for admission of water from the head water to the turbine is governed by the principle that this passage should be eased by a suitable curved surface in order to minimise hydraulic loss. The upstream ends of the piers have been rounded in circular arcs. The roof of the intake is also curved in a circular arc. The dimensions and form of the scroll case have been prescribed by the turbine manufacturers. The scroll case is also of concrete.

Low head intakes—Discharge at the gate opening.

(1)	Width of gate opening. (2) FT. IN.	Height of gate opening. (3) FT. IN.	Gross area (three openings per turbine). (4) SQ. FT.	Discharge in cusecs at rated head and capacity. (5)	Velocity at rated head and capacity. (6) FT/SEC.
Kentucky	16 6	39 0	1,902	9,000	4·73
Pickwick Landing	18 8	41 0	2,295	11,200	4·90
Wheeler	18 0	38 0	2,052	9,200	4·49
Guntersville	17 8	37 6	1,989	9,800	4·92
Chickamauga	17 8	35 8	1,893	10,700	5·65
Wattsbar	16 4	37 8	1,848	8,000	4·33
Fort Loudoun	14 8	34 6	1,518	6,700	4·00

With the unit spacing of 70–80 feet, two intermediate piers have been used in the in take. Their upstream ends have been rounded and downstream ends streamlined in an unsymmetrical manner, the form of the end of the pier being prescribed by the turbine manufacturers.

In most of the low head intakes, slots for two gates were provided, so that an emergency gate might be placed upstream if servicing of the lower gate becomes necessary.

On the tributary dams, the layouts are generally more simple as navigation locks are not required and consequently, the power-house and spillway usually have adjoining locations in the bottom of the valley at a site.

Almost all the power development of the T.V.A. have been of the direct type with the generating stations placed immediately adjacent to the dams without flumes or long pipe tunnels. However, there are two projects, Apalachia and Ocoee No. 3 in which the dams are essentially diversion dams.

The T.V.A. built plants on the main river have turbines of the propeller type except at Wheeler hydro-plant where kaplan turbines are installed which provides for the automatic adjustment of the blade angle in order to operate at the highest efficiency for the available head.

The steam plants include a modern high pressure plant built by the Authority at Wattsbar, 4 older plants, of which 3 were acquired from the Tennessee Electric Power Company and a number of small standby plants. The older plants operate at relatively low pressures and temperatures and by present day standards are obsolete. They lack adequate boiler instruments and control equipment and produce power at costs varying from about 5 to 10 mills. per kilowatt hour. However, they are very valuable for standby purposes.

The Wattsbar Steam Plant on the other hand, compares very favourably as to efficiency and overall production cost with any steam plant in the United States. This plant has 4 generating units each with a rated capacity of 60,000 KW., or a total rated capacity of 240,000 Kilowatts. Even with present-day high fuel costs, this plant produces power at a little over 3 mills. per kilowatt hour, exclusive of fixed charges.

4.3. *Layout of Power Stations.*—The position and structural relationship between the power-house and the dam has a determining effect on the layout of the power-house. The power-houses in the T.V.A. projects are classified into three types according to their location relative to the dam :—

Type I.—The power-house structure functions as a dam. Usually unit intake and unit structure are integrated into one block to resist water load. The unit intake is a reinforced concrete structure with its shape controlled essentially by its function as water entrance to the scroll case. There are seven such stations in T.V.A. of this type and all have propeller wheels and the scroll cases of all of them are of R.C.C. construction.

Type II.—The power-house is located at the toe of a concrete gravity bulk head with water conduits leading through the dam. In T.V.A. practice the 6 stations of this type use Francis turbines. All except one, the Wilson Project, use steel scroll case.

Type III.—The power-house is entirely removed from the dam. The penstock carries water into the unit substructure. These are also equipped with Francis wheels with steel scroll cases.

Relation to transformer yard and switchyard.—Electric current must flow from generators to transformers and to switchyard and bus. All these features have to be connected by control cables to the control room. Operating convenience, cost of main leads and of control cables all favour a compact location of these items. When high-tension switching facilities for a number of transmission inter-connection are to be located at the power station, the switchyard may well become the largest graded area of the project layout. If the project layout makes it difficult to provide such an area in the immediate proximity of the power station at reasonable cost, it is necessary to consider less compact layouts. In such a case the switchyard may be separated from the transformer yard. Because the low voltage generator leads are usally expensive, the transformers are located near the power-house with high tension connection between the transformers and switchyard, the latter may be moved into an area favourable for grading.

The location selected for transformers is very important. The location of the transformers on the deck over the darft tube has the advantage of providing short low-tension leads but on most T.V.A. projects, the level of maximum tail-water has prevented this utilisation. Transformers have been located on the intake deck at Pickwick and over the draft tube at Wheeler and Watauga. In most cases, it has been found expedient to locate the transformers on the bank as close to the power-house as possible and to have the switchyard adjoining the transformer yard. Structural simplicity and economy have been obtained in this respect but at the expense of loss of economy in generator leads.

A large number of units favour the outdoor type layout for economy. For stations with only one or two units, this advantage tends to disappear because the outdoor type gantry crane is considerably more expensive than the standard indoor crane.

Unit spacing.—To establish the width of the unit block, the determining factor for low or moderate head installation is usually the width of the scroll case established from hydraulic requirements increased by the pier thickness in case of concrete scroll cases or by erection clearances in case of steel scroll cases. The dimensions so obtained will ordinarily allow enough room for the draft tube below and for working space around the generators above.

The thickness of the end piers for concrete scroll cases should be from 6 to 8 feet except for steel scroll units, and erection clearance outside of steel scroll cases may be from $2\frac{1}{2}$ to 5 feet. Hence unit spacing may exceed the transverse scroll case dimension by 5 to 16 feet. For higher head plants, the generator diameter may exceed that of the scroll case so that working-clearance between generators may determine the unit spacing.

Mechanical control.—Control of the wicket gate requires servomotors, pressure tanks, oil pumps and actuating governors. To provide for instantaneous operation of the governing mechanism, the connection between the actuator and the servomotor should be as short as possible. In T.V.A. practice, the governor cabinet housing actuator and pumps are usually placed at the generator room floor level adjacent to the generator. For the outdoor type power-house, the cabinet is commonly located in the gallery close to the generator barrel. A single cabinet for two units is often employed.

Electrical equipment.—Protective equipment and low voltage switching equipment are, preferably, installed immediately adjacent to the unit. These features include the low voltage switches, breakers, instrument transformers, lightning arresters, reactors and station service connections.

Where the main control board is some distance from the unit, the boards or cubicles for direct control of the exciters or other electrical equipment associated with the unit are installed near the units.

Auxiliaries.—Certain auxiliary equipment has to be provided near each unit. Fire protection equipment (carbon dioxide system), raw water connections, including strainers, pumps and valves for the cooling of the bearings and the generator and the valves or pumps for unwatering the scroll cases and draft tube. In addition, provision has to be made at each unit for connections to the oil, air and water systems of the station.

Access and erection facilities.—Each unit block has to provide for quick walking interconnection between actuator cabinet, the turbine pit and the exciter with stairs, and passage ways, which allow convenient communication between the different generating units.

Generator room.—The generator room at Wilson is of conventional construction with high ceiling and indoor crane. The complete structure allows all works on the generating units to be done when desired without regard to weather conditions.

The same general pattern is followed in Norris, Pickwick, Guntersville, Chickamauga, Ocoee No. 3, Apalachia, Fontana, Watauga, South Holston, Halesbar and Fort Patrick Henry. The width of the generator room is determined by the diameter of the generator, and the length, by the width and the spacing of the turbine scroll case. The height of the room is determined by the crane lift necessary for the assembly of the turbines and generators.

Wheeler was built without a generator room. The generators extend above the deck of the superstructure and are housed in individual steel housings. They are served by an outdoor gantry crane which first removes the housings. A gallery below the deck contains the governor actuators, turbine gauge boards and turbine operators' desk. The design of the Boone station is of the same pattern.

A design intermediate between the entirely enclosed generator room and no generator room, often spoken of as the semi-enclosed generator room, was used at Hiwassee, Watts-bar, Cherokee, Douglas, Fort Loudoun and Kentucky. A low roof at about crane rail elevation serves also as an outdoor unloading and working deck.

The generator units are serviced by an outdoor gantry crane working over the various units and over the assembly areas. This design requires fairly low tail water conditions and favourable access elevations. It usually costs less than the fully enclosed type but sacrifices some convenience in installation and maintenance.

Cranes.—Where the generator room is semi-enclosed and as at Wheeler where the generators are outdoors the crane is of the outdoor gantry type. It travels the full length of the power-house and erection bay and serves the generating units and assembly areas through roof hatches, which it first uncovers.

Service bay.—It contains the principal assembly areas for receiving heavy machinery, unloading it and assembling the main parts. Adjacent to the assembly area are such necessary facilities as the machine shop, tool room, heavy equipment storage, station sump pumps, air compressors, lubricating and insulating oil equipment and storage tanks, CO_2 fire extinguishing equipment for the oil room, station fire pump, gasolene driven auxiliary power generator and other equipment serving the station as a whole. Usually the common auxiliary power distribution switchboard also is placed in the service bay.

Electrical bay.—This is usually located along one side of the generator room, houses the principal auxiliary electrical equipment, particularly the generator main switch-gear, neutral grounding reactor breakers, excitation breakers and rheostats, generator fire extinguishing equipment and auxiliary power transformers and distribution boards. The items associated with each generator are located in similar relation to their generator. As most of these equipments are intimately associated with the generators and as the heavy conductors from the generators to the transformers all pass through this equipment, the electrical bay is so placed as to make the electrical connections as short and direct as possible. In the main river type stations, the electrical bay is along the down stream side of the generator room over the draft tube. In some of the tributary plants, it is in the triangular section between the dam and the power-house.

Transformers.—In some cases the generator voltage is stepped up by means of three winding transformers to two voltage levels. In some other cases, it required stepping up to the voltage level that would normally carry most of the power output and using smaller transformers for stepping that voltage up or down to the other level. In either case, where two voltage levels existed at a generating station, automatic voltage regulation was usually needed for one of the system voltages and the other was regulated by the generators.

4.4. *Auxiliary power.*—Auxiliary power at 440 V is normally supplied from the main generators, through 2-duplicate 1,000 K.V.A. transformers connected to the generator leads through motor operated disconnecting switches. Each station service transformer is of adequate capacity to carry the auxiliary load of the station and in some of the later stations, this is of the Pyranol filled type.

A 12·8 K.V. rural line supplies a 600 K.V.A. emergency station service transformer. Also a 300 KVA gasolene engine driven generator furnishes emergency power to operate essential auxiliaries such as the spillway gates, the navigation lock, the pumps and the lights, in the rare event of loss of all generation and all transmission line connections.

The incoming and bus tie breakers of the auxiliary board are D.C. electrically operated, while those for the feeders are manually operated. Power from the emergency station service transformer is fed into the auxiliary power system through two electrically operated air circuit breakers.

The incoming and bus tie breakers of the main auxiliary power board are controlled from the main control bench board. Inter-locks on these breakers and double throw selector switches at the distribution centres prevent the paralleling of the auxiliary power sources.

Duplicate feeders to important load centres and duplicate or alternate equipment for essential auxiliaries ensure continuous operation of the auxiliary services and also permit the retirement of parts of the auxiliary power system for inspection and maintenance without curtailing the operation of important equipment.

All auxiliary power boards are of the dead front, safety enclosed type, of ⅛ inch thick steel with black exterior finish and light grey interior.

All breakers on the main auxiliary power board are of the air break type and have an interrupting rating of 20,000 amps. Circuits direct to loads are controlled by fused knife switches and contacts with thermal overload elements. Individual motors and heaters are controlled at the respective destinations.

The auxiliary power sources consist of step-down tranformers connected to two of the main step-up transformers and usually a smaller step-down transformer connected to a nearby sub-transmission voltage line connecting to a distant generating station or sub-station. A small emergency gasolene engine driven generator set is also installed in several of the stations.

The auxiliary power transformers are usually located outdoors adjacent to their sources of supply or indoors near the main auxiliary power switchboard. The main auxiliary power switchboard located in the service bay or electrical bay receives the output of these sources and distributes it to a number of common and unit distribution boards located at load centres throughout the dam, power-house and switchyard.

Auxiliary supply.—The table below gives an indication of actual connected loads and measured demands, taken from four typical stations—

TABLE 5.

Stations.	Kentucky.	Fort Loudoun.	Fontana.	Apalachia.
Type of development	Main River.	Main River.	Tributary.	Diversion.
Station capacity in KVA	175,000 in 5 units.	142,222 in 4 units.	225,000 in 3 units.	80,000 in 2 units.
Motors—				
Number	126	105	68	55
H.P.	2,511	1,789	1,096	566
Heating—				
Number	53	49	45	30
K.W.	888	722	771	351
Lighting—				
Transformers K.W.	395	388	386	205
Lamps K.W.	301	216	270	113
Total connected load K.V.A.	3,810	2,520	2,140	1,038
Measured demand K.V.A.	1,010	766	563	252
Measured P.F.	0·74	0·75	0·81	0·84
Transformer capacity K.V.A.	1,250	1,000	1,000	450

Assumes average motor efficiency as 86 per cent and P.F. 0·77.

Auxiliaries.—A 250V. 50 amps. 8 hour, 480 amps. 1 min. storage battery with 2-130 K.W. M.G.,charging sets are provided for control operation,continuous operation of the emergency lighting system and standard frequency M.G. set. Automatic synchronizing equipment is provided. This includes speed matches with suitable protective features to prevent closing of control circuit unless the phase angle and voltage are correct.

Supply circuits for the station clocks and chart drive motors of recording instruments are connected through small circuit breakers to 115V. 60 cycles emergency A.C. power bus normally energised from a station service supply circuit. If this supply fails, automatic equipment starts a M.G. set and transfers the load from the station service supply to the generator. A 60 cycle tuning fork with amplifiers provide an accurately controlled frequency source of limited output for operating the station frequency controlling equipment, time error indicator, master frequency clock, recorders, etc.

4.5. *Control room.*—The control room location most desired is in the service bay or electrical bay where it is central between the controlled equipment in the power-house and the switchyard. It generally was considered more important to provide a short, direct traffic route from the control room to the switchyard than to the generating units since the control operators are expected to patrol the switchyard and operate the disconnecting switches, etc., while operations and observations around the generating units are the responsibility of the turbine operators. It generally was found preferable also to route the control cables and conduits from the control room to the power-house in this direction and to the switchyard in the opposite direction, rather than to merge them in one direction.

When economy of control room alone is taken into consideration, the control room should be located at the point where the total length of the control cables becomes a minimum.

At Wattsbar, where the switchyard is very large and requires a greater number of conduits than the generating units the control room is located in a separate building near the switchyard. From an operating standpoint, the control room should have convenient access from the outside or from other operating areas and if possible from the switchyard. On small stations, it should be close to the generating area.

T.V.A. practice is to make the control room as nearly sound proof and vibrationless as possible and to air-condition it so as to ensure accurate readings of the instruments.

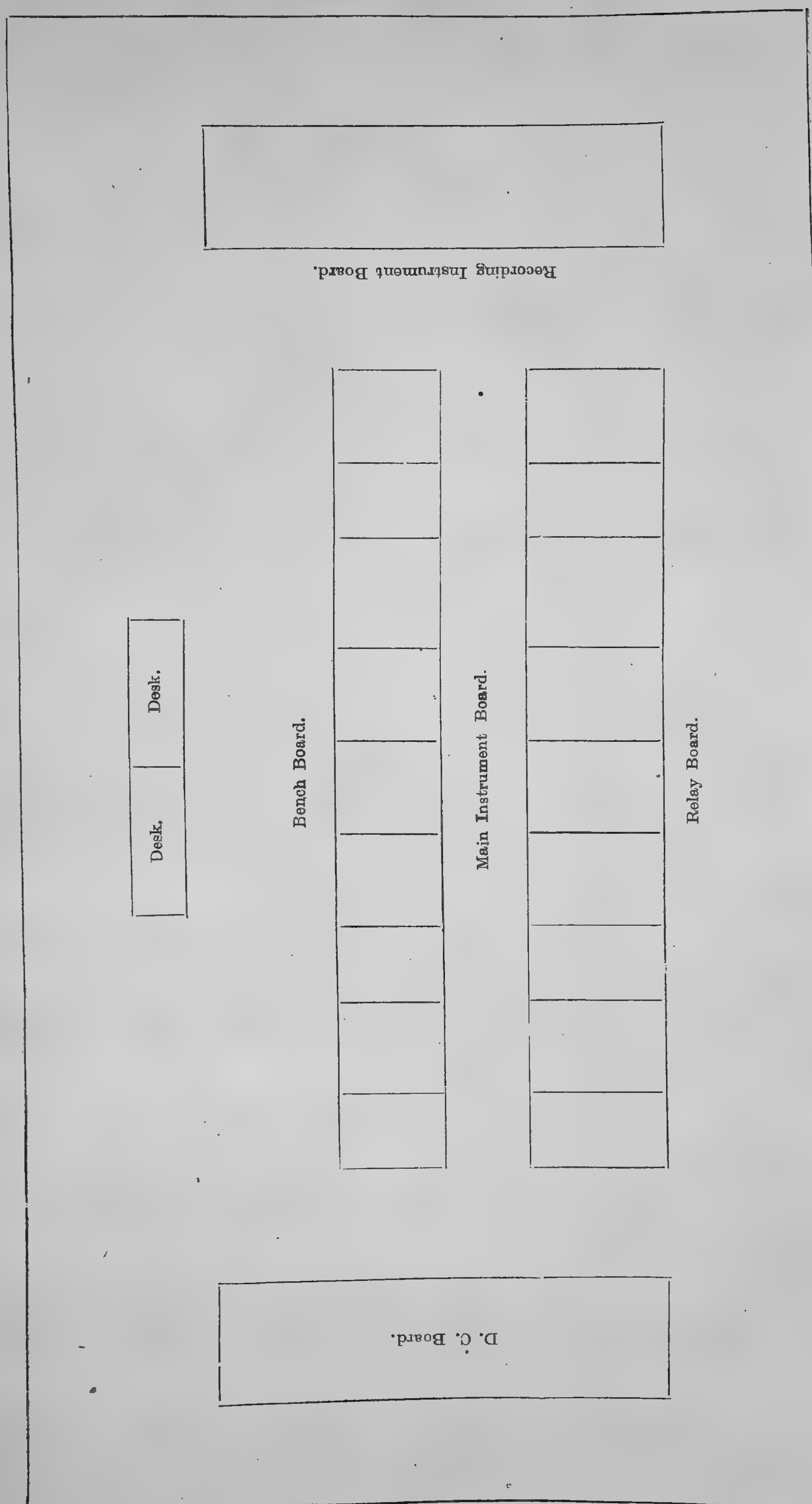
For routing of the cables connecting the units and switchboard to their proper boards in the control room, a spreading room about the same size as the control room is provided immediately below the control room. These cables are carried in trays and pass upward through slots in the floor.

On smaller stations, the trays may be suspended from the ceiling with the floor below assigned to other uses. In larger stations, the room is assigned exclusively to cable spreading.

In T.V.A. practice, the cables connecting with the unit blocks are carried on trays in a cable gallery, while for connection with the switchyard, either trays in the cable tunnel or buried conduits in duct lines are used.

The control of all major power-house and switchyard electrical equipment is centralized at the control bench board and vertical back to back instruments and relay boards in the control room. The battery control, standard frequency system and load frequency controls are also located in the main control room.

The governor actuator with their combined gauge and control boards for the control of the turbine is located on the generator room floor between the units. An excitation cubicle for each generator located in the electrical bay near the generator contains the main exciter and pilot exciter rheostats and the voltage regulator contacts.



Switchboard and Recording Instruments Board, Cherokee Project.

Cherokee Project—Recording Instrument Board.

Panel.

(1)	(2)	(3)	(4)
River level indicator.	154 KV. recording voltmeter.	Master controller.	Generator 1 load controller.
Forebay water level recorder and indicator.	Frequency recorder.	Tie line load controller.	Generator 1 and transformer temperature recorder.
Tail race water level recorder and indicator.	Master load control receiving and retransmitting recorder.	Station load recorder.	Generator 1 field temperature recorder.

Panel.

(5)	(6)	(7)	(8)
Generator 2 load controller.	Generator 3 load controller.	Generator 4 load controller.	..
Generator 2 temperature recorder.	Generators 3 and 4 temperature recorder.	Transformer 2 temperature recorder.	Future automatic synchronizing.
Generator 2 field temperature recorder.	Generator 3 field temperature recorder.	Generator 4 field temperature recorder.	..

4.6. *Auxiliary mechanical equipment.*—If the size and arrangement of the service bay is such that one or two floors of sufficient size can be made available for this equipment (viz., lubricating and insulating oil pumps, raw water strainers, pumps, fire protection, etc.), at a level below the generator room floor, a very economical and convenient layout for all auxiliary mechanical features can usually be obtained. With such arrangement, lubricating oil will drain from the bearings by gravity. Gravity feed of raw water can be obtained and the pipe connexions to the units can be made easily by means of a pipe gallery at the level of one of the floors.

4.7. *Scheme of switching and connexions.*—The simplest scheme is to connect each generator through its individual two winding three phase transformer or bank of three single phase transformers to a single high voltage system with no generator load except station service. This is in use at Norris, Pickwick, Wattsbar and other plants. Synchronizing is done on the high voltage breakers. A motor operated disconnect electrically interlocked with the transformer high voltage breaker is provided in the main circuit of each generator for purpose of isolating and testing.

As the power system expanded, the outage of two generators in the rare event of transformer trouble could be tolerated and the greater economy of connecting two generators per transformer bank was accepted. This is in use at Wheeler, Wilson, Cherokee, Douglas, Fort Loudoun and Halesbar.

Generator breakers are required for synchronizing and for switching generators with changes in station load.

Three winding transformers were required for all or part of the generators at Chickamauga, Ocoee No. 3, Fort Loudoun, etc., to supply two transmission systems in each case.

Each of the normal station service transformers generally is connected to its generator transformer circuit between the generator disconnect and the delta bus, so as to supply station service load either from the generator or from the power system. The circuit

is interrupted by an air circuit breaker on the 480 V bus. The motor operated disconnect at the 13·8 KV end is interlocked with the 480 V breaker to prevent operation under load. At Wheeler where the station service transformers serve considerable 2,400 V station service and village load, a breaker is provided on the 13·8 KV side of the station service transformer.

With bare conductor construction, the conductors are mounted on porcelain bus supports, and for indoor circuits, the three phases are enclosed in a housing for safety of operating personnel. The housings are of non-magnetic material or translite and barriers between phases are of the same material. Circuits from switchgear units in the electrical bay of the power-house to the transformers in the switchyard for these relatively short runs are usually carried on the walls or ceilings of a concrete tunnel. At Apalachia, where the transformer yard adjoins the power-house, the bare conductors extend through wall bushings and on overhead structures to the transformers.

Joints in bare conductors, except expansion joints, are welded or brazed. For copper oxy-acetylene brazing process has been used and for aluminium, the inert atmosphere (argon) arc welding process has been used. The expansion joints consist of standard braided or laminated copper or aluminium joints bolted to the conductors. The contact surfaces of the bolted joints are silver plated if the bus and expansion joints are of copper and are treated with a non-corroding air excluding paste if of aluminium.

Ventilation of the housings enclosing the bare conductor circuits is provided by blowers in cases where sufficient circulation of air by gravity alone cannot be assured.

The switching permits operating the entire auxiliary power system on either of the two normal auxiliary power transformers or dividing it between the two. Automatic switching from one source to another in case of loss of voltage is not considered desirable for an attended station, because it adds complexity to the controls and relaying and because the momentary loss of auxiliaries does not ordinarily shut down a unit or cause loss of load.

For unattended stations, however, the transfer from one normal source to the other in case of loss of voltage is accomplished automatically.

If a transfer of load is to be made from one source to another, either manually or automatically the load is always disconnected from one source so as to avoid paralleling the two sources. The momentary interruption is considered more acceptable than the possibility of a surge resulting from a momentary paralleling.

4.8. *Power-house building—Wattsbar.*—The power-house is a semi out-door type with the power-house gantry crane operating on the roof of the enclosed generator room. The structures for each generating unit and for the service bay are independent units separated by contraction joints extending from the foundation to the roof. The sub-structure is the conventional low head type and is connected to the intake so that, together they form a manolith to resist the water loads.

The control building is located on the top of the bluff on the right river bank, overlooking the power-house. The main power-house crane which is of the out-door type has a cantilever attachment for lifting 20-tons for use in lifting the tail race gates.

The dimension from the longitudinal centre line of units to the down-stream face of the turbine block is governed by the requirement of a reasonable minimum thickness of wall at the farthest down-stream point of the scroll case which is concrete.

The scroll case is designed to prevent shrinkage cracks in the concrete faces and to withstand the bursting force of the water under head pressure. It is also designed for external tail water pressure when the turbine is unwatered, for a dead load together with a live load of 1,000 lb./sq.ft. on the roof slab.

There is no draft tube gantry crane and the draft tube gates are operated from a boom hoist mounted on the power-house gantry crane.

Each unit is divided into a fore-bay well and a screen well by a bulk head wall. The intake opening in the head wall of the forebay well is protected by a trash rack installed between vertical wide flange beam guides attached to the piers. The trash racks are designed for a differential head of 5 feet and a relatively low velocity of about 3·5 feet per second. To prevent all but very small pieces of debris from entering the intake conduit, each screen well is fitted with a small mesh revolving screen, which in its operation is automatically cleaned at the operating floor. Trash from the screen falls into a trash gutter and is slushed to tail water through a 24 inches diameter pipe built into the sub-structure of the service bay.

The roof over the electrical bay and generator room consists of pre-cast concrete slabs supported on beams and girders.

The large hatch openings in the roof are covered by removable covers built-up above the deck to provide ventilation to the generator room.

4.9. *Technical characteristics.*—The following table gives the technical characteristics of the turbines and the generators installed in some of the main generating stations of the Tennessee Valley Authority :—

TABLE 6.—*T.V.A.*

	Apalachia.	*Chickamauga.*	*Fontana.*	*Guntersville.*
1 Drainage area and above	1,018 square miles	20,790 square miles	15,715 square miles	24,450 square miles
2 Average flow at dam	2,000 cusecs	36,500 cusecs	3,700 cusecs	42,000 cusecs
3 Head maximum	440 feet	55 feet	433 feet	45 feet
4 Average	415 feet	45 feet	429 feet	37 feet
5 Minimum	385 feet	3·5 feet	248 feet	5 feet
6 Dam	Non-over flow concrete gravity section, concrete gravity spillway section.	Concrete spillway section, concrete power house intake section, navigation lock, earth embankment.	Concrete gravity including main spillway.	Concrete gravity spillway section, concrete power house intake section, navigation lock and earth embankment.
7 Length of Dam	1,308 feet	5,800 feet	2,365 feet	3,979 feet
8 Height of Dam	150 feet	129 feet	430 feet	94 feet
9 Generating units	2 × 37,500 KW	4 × 27,000 KVA	3 × 67,500	4 × 24,300 KW
10 Maker's name of the turbine	Baldwin	Baldwin	Allis Chalmers	Morgan Smith
11 Maker's name of the generators	Westinghouse	Allis Chalmers	Westinghouse	G. E.
12 Spacing of turbine, centre to centre.	44 feet	80 feet	56 feet	78 feet
13 Dimensions of the Power House—				
Length	147 feet	426 feet	205 feet	406 feet
Breadth	87 feet	170 feet	72 feet	168 feet
Height	98 feet	170 feet	127 feet	166 feet
14 WR^2 of the turbine	$0{\cdot}5 \times 10^6$	$6{\cdot}7 \times 10^6$	$2{\cdot}72 \times 10^6$	$6{\cdot}2 \times 10^6$
15 Shaft diameter	25 inches	33·5 inches	34 inches	35 inches
16 Type of guide bearing	Oil lubricated	Water lubricated	Oil lubricated	Water lubricated
17 Type of scroll case	Cast steel	Concrete	Plate steel, welded	Concrete
18 Gate servomotors—				
(a) Capacity, cubic inches	7,860	20,300	12,000	14,700
(b) Operating pressure	250 to 300 lb. per-sq. inch.			
(c) Minimum time to close, in seconds.	6	6	6	6
19 Blade servomotors—				
(a) Capacity in Cubic inches	....	21,200	....	24,400
(b) Minimum time to open or close.	....	8 seconds	....	8 seconds
(c) Maximum time to open or close blades.	....	40 seconds	....	40 seconds
20 Type of draft tube	Elbow	Elbow	Elbow	Elbow
21 Governor—				
(a) Maker's name	Woodward	Woodward	Allis Chalmers	Woodward
	Cabinet actuator	Cabinet actuator	Cabinet actuator	Cabinet actuator

Generating Stations.

Norris.	*Wattsbar.*	*Wheeler.*	*Wilson.*	*Kentucky.*
2,912 square miles	17,310 square miles	29,590 square miles	30,750 square miles	40,200 square miles.
4,100 cusecs	26,400 cusecs	49,000 cusecs	50,500 cusecs	65,000 cusecs.
214 feet	60·5 feet	52 feet	96 feet	73 feet.
194 feet	56 feet	48 feet	93 feet	47 feet.
129 feet	40 feet	40 feet	69 feet	6 feet.
Non-overflow concrete gravity section. Concrete gravity spillway section, earth fill section with concrete core wall.	Concrete gravity spillway section and non-overflow section. Concrete power-house intake section, navigation lock, earth embankment section.	Concrete gravity spillway section. Concrete power-house intake section, navigation lock, non-overflow section.	Concrete gravity spillway section. Concrete power-house intake section. Navigation lock, concrete bulk head section.	Concrete gravity spillway section, concrete power-house intake section. Concrete navigation lock, earth embankment.
1,860 feet	2,960 feet	6,342 feet	4,862 feet	8,422 feet.
265 feet	112 feet	72 feet	137 feet	206 feet.
2 × 50,400 KW	5 × 30,000 KW	8 × 32,400 KW	18 sets of a total of 436,000 KW.	5 × 32,000 KW.
New Port News Ship-building company.	Baldwin	Baldwin	Allis Chalmers I. P. Morris	Allis Chalmers.
Westinghouse	Westinghouse	G. E.	G. E., Westinghouse and Allis Chalmers.	G. E.
60 feet	73 feet	76 feet	55·5 feet	77·5 feet.
205 feet	470 feet	868 feet	1,198 feet	477·5 feet.
71 feet	139 feet	181·5 feet	68 feet	152 feet.
125 feet	133 feet	125 feet	134 feet	151 feet.
$2{\cdot}6 \times 10^6$	$3{\cdot}61 \times 10^6$	$4{\cdot}5 \times 10^6$	$2{\cdot}57 \times 10^6$	$3{\cdot}15 \times 10^6$
35 inches	32 inches	33·5 inches	47·25 inches	34 inches.
Oil lubricated	Water lubricated	Water lubricated	Water lubricated	Water lubricated.
Plate steel, rivetted	Concrete	Concrete	Concrete	Concrete.
16,900	18,000	24,000	8,400	18,600.
		(250 to 300 lb. per sq. inch)		
6	6	6	6	6.
....	23,600	....	....	30,000.
....	8 seconds	....	....	8 seconds.
....	40 seconds	....	....	40 seconds.
Elbow	Elbow	Elbow	Moody cone	Elbow.
Woodward	Woodward	Woodward	Allis Chalmers	Allis Chalmers.
Cabinet actuator	Actuator type cabinet	Cabinet actuator	Cabinet actuator	Actuator cabinet type.

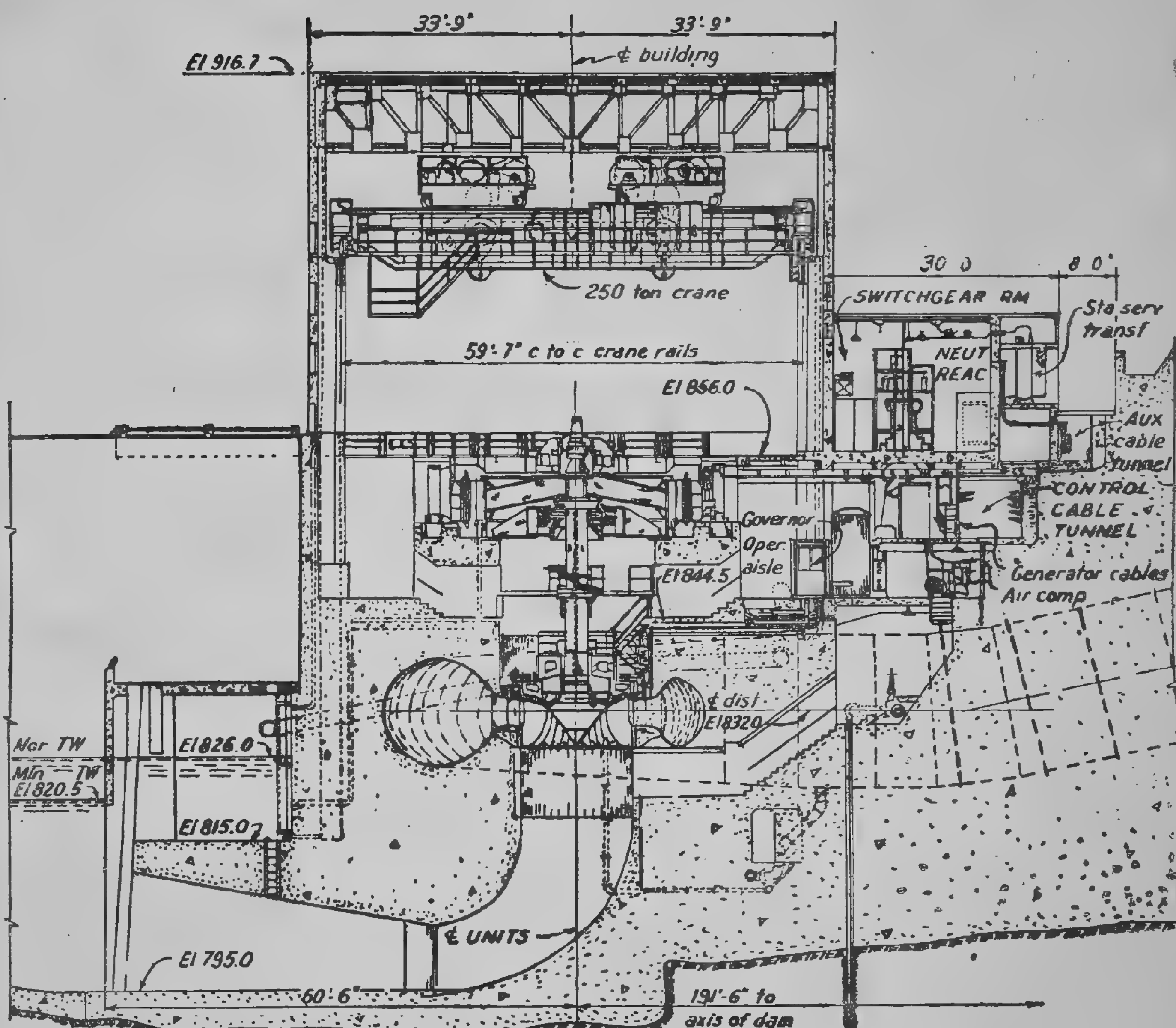
4.10. *Chickamauga.*—The number of units, size and type of equipment and its operating characteristics are dependent upon many factors. These include maximum static head, minimum head during floods, effective operating head at the plant during average and critically dry periods, the potential primary, secondary and dump power available at the plants and the relative value of such classes of power, the energy and peak demand of the system, the outage of the generating units and the system reserve capacity requirements ; the desired plant load factor and plant capacity factor, the comparative cost of providing generating capacity at the individual plant in relation to the cost at other plants of the system.

The general hydraulic and structural requirements for the intake are as follows :—

Each bay must provide water passage to the turbines ; the flow must enter the structure at a low velocity and accelerate to suit the requirements of the scroll case. The structure must form a stable part of the dam and it must carry safely the dead load of the structure, the dead and live loads from a portion of the Power-house, the loads of the gantry cranes operating on the deck, etc.

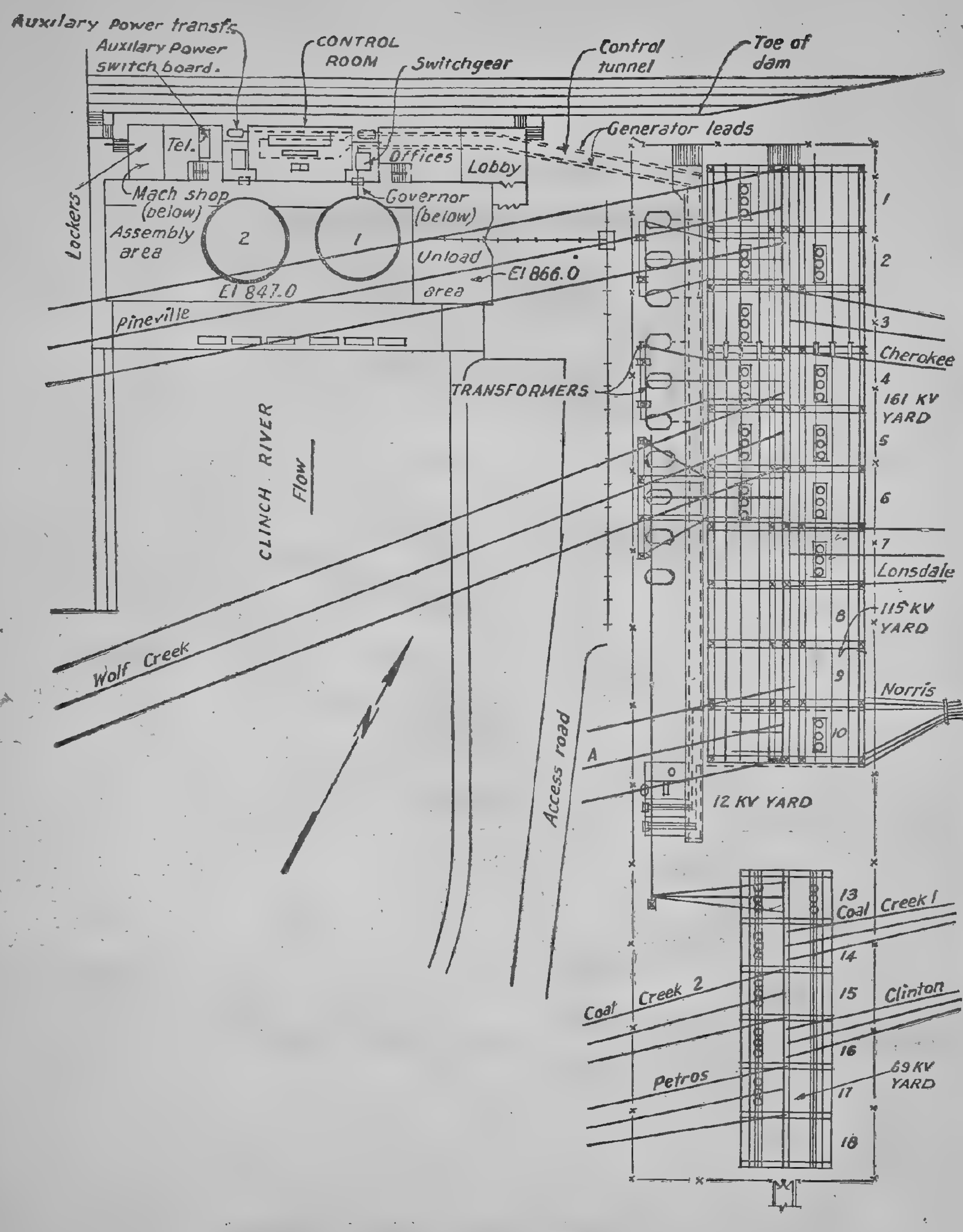
The Power-house is of the enclosed type. The tail water here may rise as much as $32\frac{1}{2}$ feet above the generator room floor.

4.11. *Norris Power House.*—Sketches P.S. 30 and P.S. 31 show the Power-house Section and the Power-house and Switchyard plan of the Norris Power Station.



NORRIS POWERHOUSE SECTION

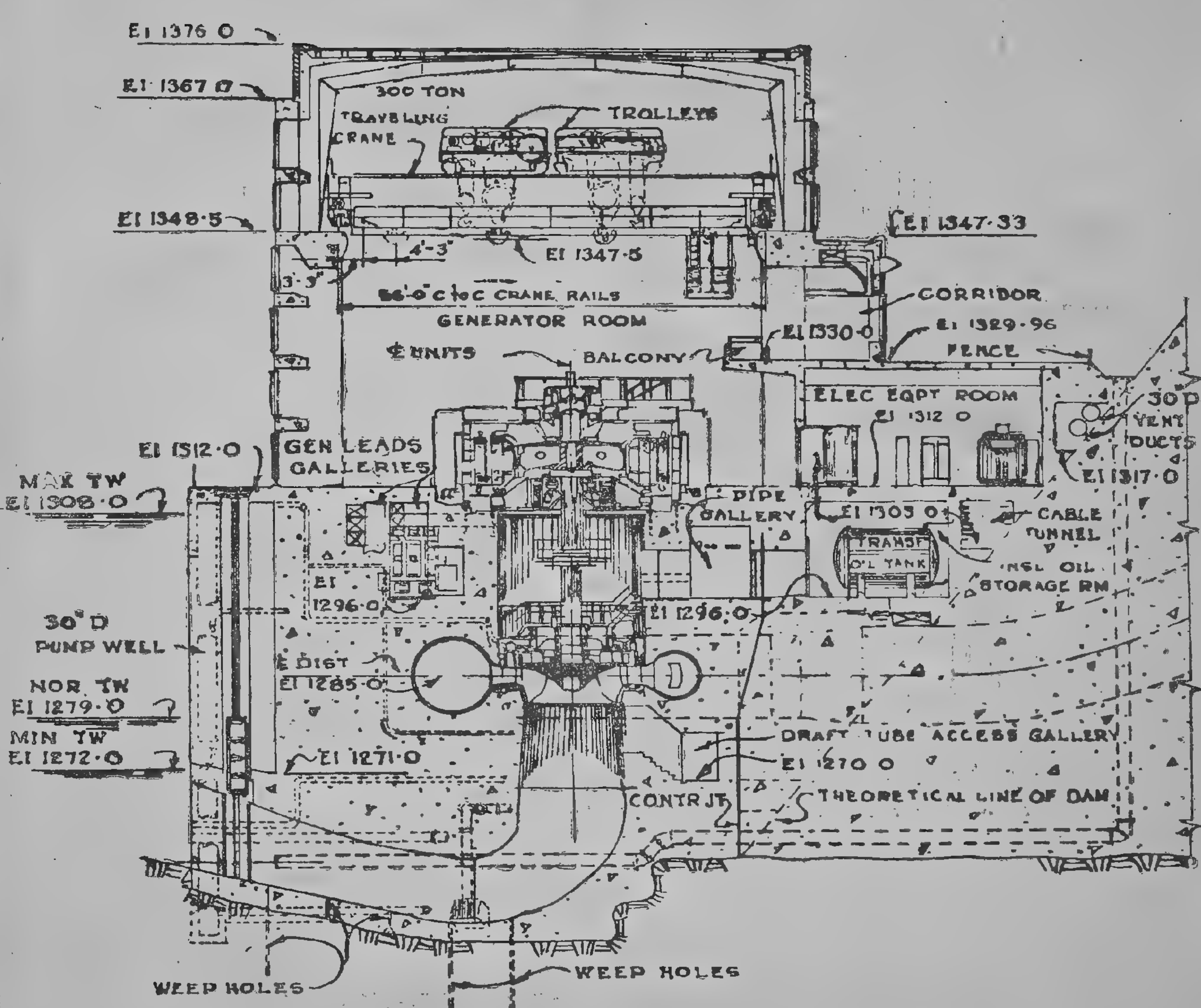
SKETCH P.S. 30.



NORRIS POWERHOUSE AND SWITCHYARD PLAN.

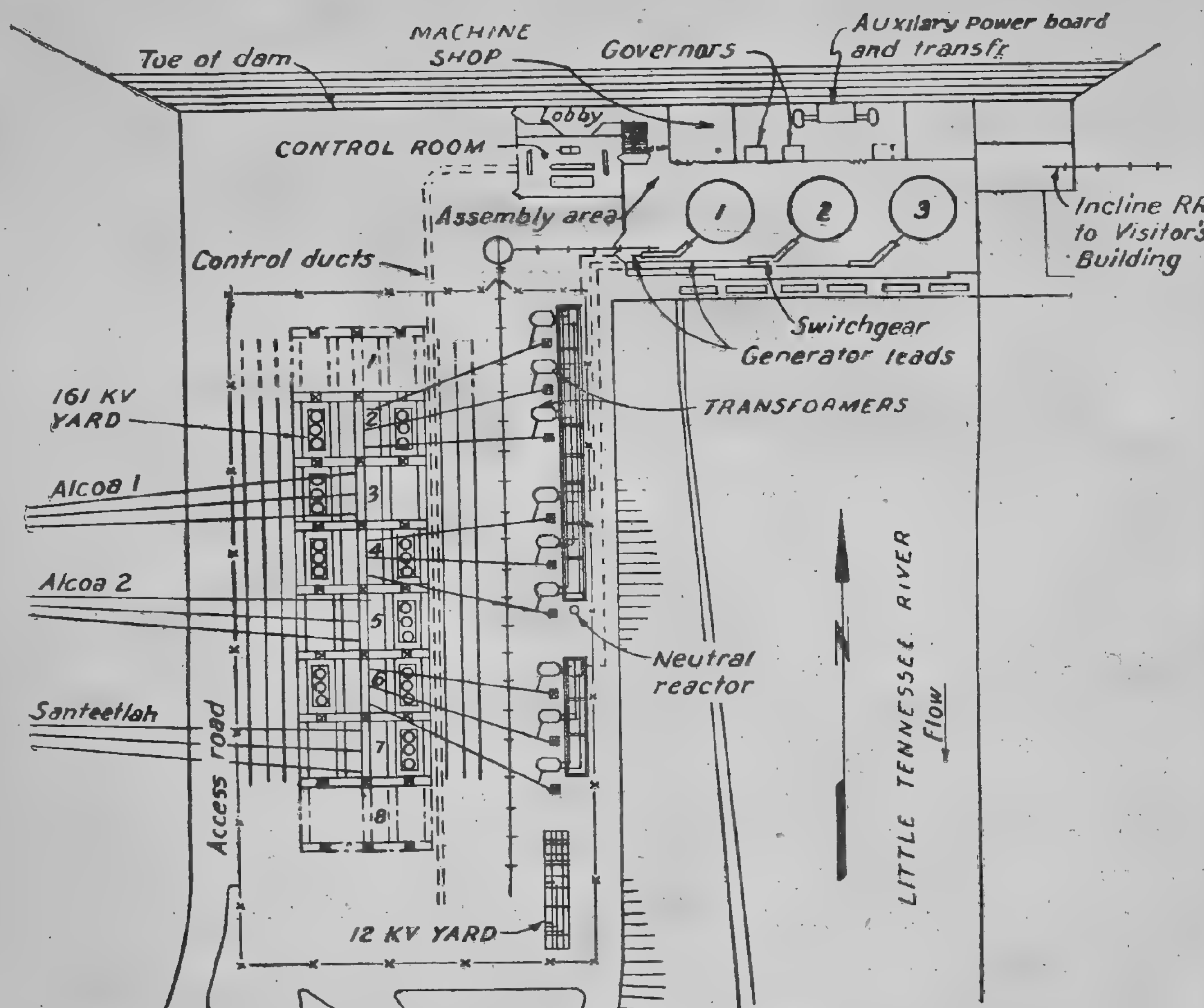
SKETCH, P.S. 31.

4·12. *Fontana Power-house.*—Sketches P.S. 32, P.S. 33 and P.S. 34 show the Fontana Power-house section, its Power-house and Switchyard plan and single line wiring diagram of the ultimate development respectively.



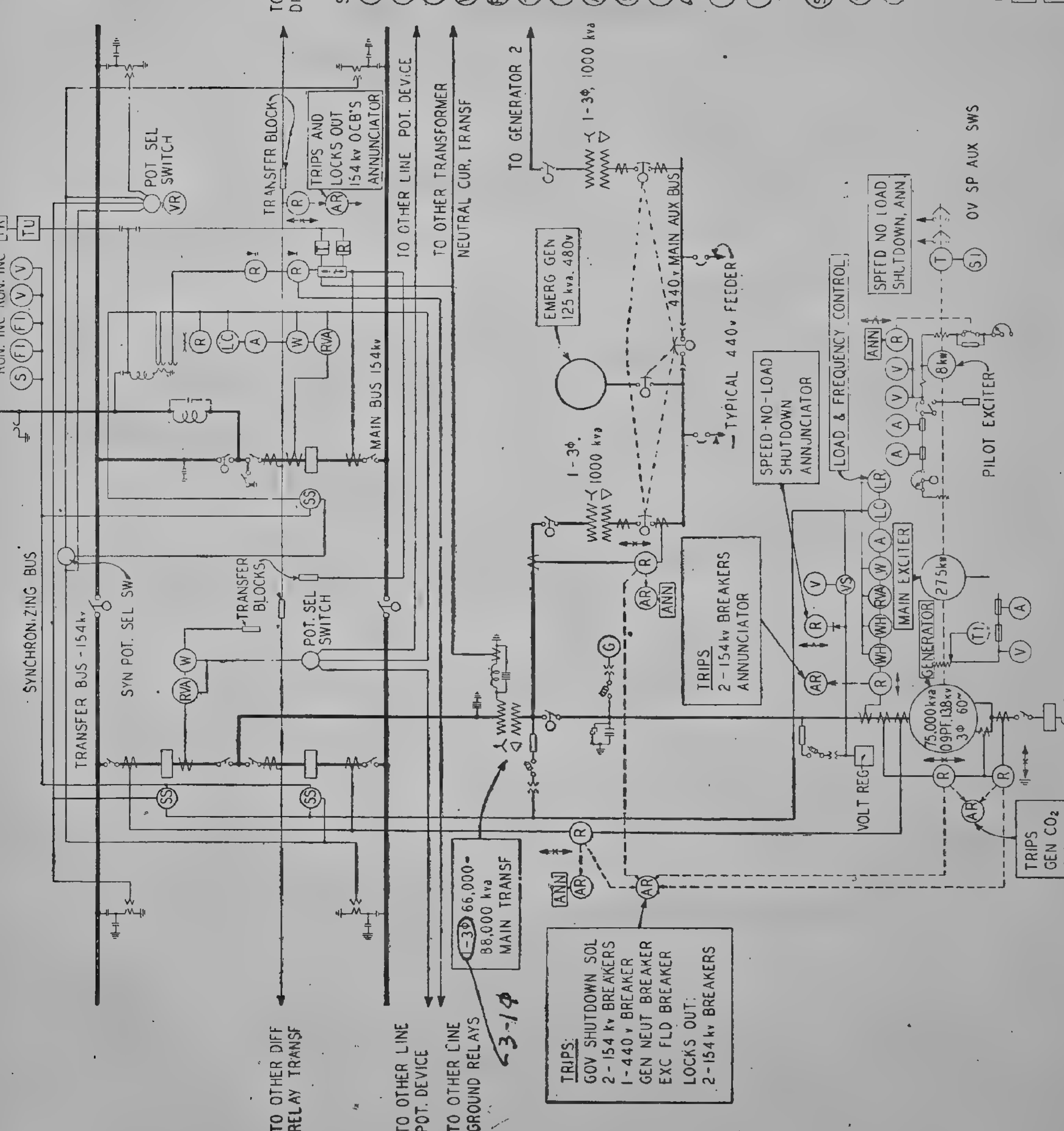
FONTANA POWERHOUSE SECTION

SKETCH P.S. 32.



FONTANA POWERHOUSE AND SWITCHYARD PLAN.

SKETCH. P.S. 33.



MAIN SINGLE LINE WIRING DIAGRAM
(FONTANA ULTIMATE)

SKETCH P.S. 34.

4.13. *Apalachia and Ocoee No.* 3 *Power Stations.*—These are two projects in which the dams are essentially diversion dams and the water is carried to the generating station through long tunnels in rock. These tunnels are constructed close to the minimum hydraulic gradient to a point above the power-house and from this point steel penstocks exposed to open air conduct the water from the tunnels to the generating units.

Apalachia.—The larger of these projects is Apalachia where the average head is 415 feet with a maximum of 440 feet. The diversion line consists of about 35,600 feet length of 18 feet diameter lined tunnel, 6,000 feet length of unlined tunnel and 200 feet length of 16 feet and 18 feet steel penstock or liner. Maximum discharge through the tunnel is 3,200 cusecs, giving a velocity of 13 ft./sec. in the concrete portion. The lining was omitted in the 6,000 feet length of the tunnel as the quality of rock in this section was better than the average.

The details of the penstocks of this project are as follows :—

Diameter—11 feet.

Area—95 square feet.

Discharge—1,500 cusecs.

Velocity—15·8 feet/sec.

Maximum discharge—1,850 cusecs.

Maximum velocity—19·5 ft/sec.

With such a large discharge on so long a tunnel, a large surge tank was necessary and the tunnel alignment was so fixed that this tank could be constructed by excavating it in the top of the hill adjoining the power-house. The surge tank is 235 feet deep 66 feet in diameter and of the Johnson differential type. It has a steel riser 16 feet in diameter extending 214 feet above the bottom of the tank.

Ocoee No. 3.—This is the other tunnel project of the T.V.A. The tunnel is 13,000 feet long and except for 500 feet of steel lined circular section, is of 12½ feet horse-shoe section fully lined. It carries about 1,200 cusecs of water to operate the plant under 313 feet head. The surge tank is of steel 40 feet in diameter and 142 feet high resting upon a rock foundation, a short distance above the tunnel.

The penstock details of this project are as follows :—

Diameter—11 feet.

Area—95 square feet.

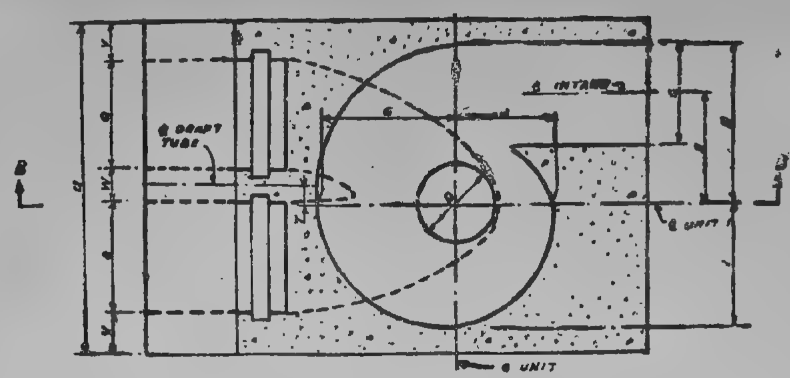
Discharge—1,200 cusecs.

Velocity—12·7 ft./sec.

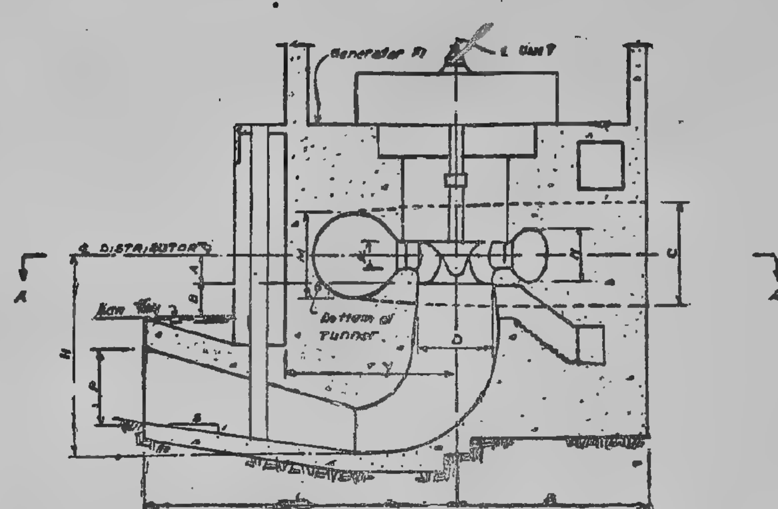
Maximum discharge—1,550 cusecs.

Maximum velocity—16·4 ft./sec.

4.14. Dimensions and data for runner, scroll case and draft tube of the turbines at Apalachia, Cherokee, Fontana, Norris and Ocoee are given in Sketch P.S. 35.



PLAN A-A



SECTION B-B

WATERWAYS DIMENSIONS AND DATA FOR FRANCIS-TYPE RUNNER

SKETCH P.S. 35

DATA	PROJECTS				
	APALACHIA	CHEROKEE	FONTANA	NORRIS	OCOEE Nº 3
TURBINE					
CRITICAL HEAD, FEET	262	98	305	168.5	272
HORSEPOWER AT CRITICAL HEAD	53,000	41.500	81,500	66,000	33,500
CUBIC FEET PER SECOND AT CRITICAL HEAD	1,800	4.400	2,880	4,300	1,200
SPEED, REVOLUTIONS PER MINUTE	225	94.7	150	112.5	200
SPECIFIC SPEED	33	68	32	49	32
RUNNER:					
DISCHARGE DIAMETER ... D	8.58	14.83	12.08	13.79	8.09
CENTERLINE TO BOTTOM OF RUNNER ... A	3.01	5.11	3.98	4.61	2.28
BOTTOM OF RUNNER TO LOW TAILWATER ... B	4.39	−0.11	2.02	1.42	4.77
DIRECTION OF ROTATION	COUNTER-CLOCK WISE	COUNTER-CLOCKWISE	CLOCK WISE	CLOCK WISE	CLOCKWISE
SCROLL CASE:					
INTAKE DIAMETER ... C	9.00	19.00	12.00	17.67	9.00
HEIGHT ... K	1.60	4.66	2.42	3.50	1.32
HEIGHT ... M	7.30	15.69	10.40	14.06	7.51
HEIGHT ... N	3.80	8.78	6.10	9.00	5.00
DRAFT TUBE:					
HEIGHT ... H	24.42	37.00	35.00	37.06	25.00
LENGHT ... L	36.50	59.12	50.00	57.00	30.06
OUTLET WIDTH ... Q	10.88	20.25	19.75	14.00	11.17
OUTLET HEIGHT ... P	9.67	13.75 15.75	12.50	15.84	7.28
SLOPE ... S/T	5.30	6.74	4.27	0.00	8.60
OFFSET ... T	0.00	3.00	2.00	0.00	0.00
RATIOS:					
C/D	1.05	1.28	0.99	1.28	1.11
E/D	1.35	1.36	1.38	1.45	1.51
$\frac{F+I}{D}$	3.36	3.52	3.44	3.53	3.70
G/D	1.69	1.78	1.74	1.79	1.88
H/D	2.85	2.49	2.90	2.68	3.10
L/D	4.25	3.98	4.14	4.13	3.72
P/D	1.13	0.093 1.034	1.034	1.15	0.9
U/D	5.13	4.11	4.64	4.35	5.75
SCROLL CASE INLET AREA	63.60	283.38	113.04	245.10	63.60
DRAFT TUBE END AREA	210.42	597.60	487.50	665.28	162.6

4·15. *Drainage systems.*—Power-house drainage is discharged entirely into the station sump. The power-house septic tank effluent, and the filter plant back-wash waste discharge directly to tail water normally but during periods of high tail water is by-passed into the station drainage and unwatering pump.

Drainage from the power-house roof and service bay deck is discharged directly into the forebay. The station sump is located in the basement of the service bay. It has a capacity of 28,350 gallons and is served by 2-300 gpm pumps discharging directly to tail race. These pumps have 7½ h.p. vertical motors and are operated automatically by float controls.

Drainage from the spillway gallery is normally discharged to the station sump through a 12 inches drain line. If an excessive amount of leakage collects in the gallery during periods of high water, it may be necessary to allow the gallery to fill up to the tail water level by closing the valve in the 12 inches line to the sump. Normally open valves located in wells in spillway piers allow this excess leakage to equalize to the tail water and in this way they prevent any build up of pressure or uplift on the spillway structure greater than that produced by tail water. This equalizing system also prevents any possibility of flooding portions of the power-house which would otherwise occur if the capacity of the pump is exceeded.

Drainage of the water passage in the screen house passes directly to tail water and can be fully discharged only when the tail water is at its normal level.

The turbine pit in each unit is unwatered by a 1-inch jet eductor discharging into the drainage system to the station sump.

4·16. *Load and frequency control—Load frequency control.*—Soon after T.V.A. first generated power at its hydro-electric plants, it established major inter-connection with the neighbouring utilities to effect the several substantial economies that are possible with co-ordinated operation of a large predominantly hydro-electric generating system with a large predominantly steam generating system. T.V.A., therefore, became part of a very large group of inter-connected systems which now extends in the west to Cody, Nebraskee in the east to Harrisbarg, Pennsylvania in the north to the Great Lakes and in the South to the Gulf of Mexico. The total installed capacity of this inter-connection, now, is in excess of 25 million KW.

In order to realize the advantages and economies of inter-connected operation, the power interchange on all lines between systems must be controlled at pre-arranged scheduled values. This can be accomplished only by changing generation at one or more of the generating stations on each system as area loads change. In order to obtain the best overall operation, these changes in generation are made automatically by means of the load frequency control equipment installed in a number of the main power plants of each system. Essentially the equipment operates on the governor control motors of selected generating units in response to load and frequency variations at selected points on the power system.

In addition to maintaining reservoir levels strictly within the limits of the predetermined schedules required for flood control, navigation and other regional services, T.V.A. has normally been responsible for maintaining its scheduled power interchange on certain of the inter-system ties. Consequently, it has been necessary to install load frequency control equipment at several of the major plants on the T.V.A. system as the selection of the stations used for regulation varies from time to time as the system load and water conditions change.

The load dispatcher who is located at Chattanooga is provided with the necessary recording instruments so that he knows exactly what is happening on the ties and at the generating plants. With such information as river flow conditions, anticipated run off data,

water release and with the instructions provided by the T.V.A. river control office in Knoxville, the load dispatcher selects the plants to be assigned for regulation and instructs the operators in these plants, when and how to place their automatic control in service.

The information, which the load dispatcher receives regarding the power system, falls into three general classifications. First, readings are provided of the power interchange on all the ties to neighbouring systems. Certain of the readings are totalized so that the dispatcher can tell at a glance what the total interchange may be on a selected group of lines, since quite often a totalised net interchange reading is his best operating guide. Second, the instantaneous system frequency is recorded on a separate instrument. This measurement keeps him continually advised on how the generation and load compare on the inter-connection as excess generation will cause high tie line loads and a deficiency of generation will cause low tie line loads. The third group of readings provided, consist of the generated output of certain of the main generating stations. All these load readings are measured at the various metering points, which may be hundreds of miles from the dispatching office and are transmitted by carrier telemetering equipment to Chattanooga.

At the present time, the regulating practice consists first of obtaining the proper combination of the line interchange readings and the system frequency so that the dispatcher knows at all times whether or not the generation on his system is meeting the requirements, and second of changing generation somewhere on the system to maintain the correct scheduled tie line loading conditions. Experience has proved that a given interchange schedule in megawatts should be maintained only when the system frequency is 60 cycles and that as the frequency varies, the actual interchange on any particular tie should be shifted by a predetermined amount in a direction to restore the frequency to 60 cycles. The type of automatic control that makes this possible is known as the line-load-bias control, and this is used in many systems at the present time. The bias is always stated in megawatts per 0·1 cycle of frequency change and denotes the amount of shift from schedule that will be made in the line control point as the system frequency varies.

On the T.V.A. system, the dispatcher is provided with a deviation from schedule measurement which usually consists of first the algebraic sum of the selected tie line interchange readings, second the desired schedule on these ties and third the frequency bias. A glance at this instrument shows the dispatcher whether or not the T.V.A. system is meeting its operating requirements. Two such deviation-from-schedule recorders are in use at present and either can be used.

The purpose of the load frequency control equipment installed at the main hydro-plants is to vary the generation in order to maintain the deviation from schedule reading at zero. The dispatcher is able to select the desired deviation from schedule reading by switches and transmit the information to one or more of the generating stations by carrier. The various carrier channels used for this purpose are referred to as numbered "Master channels" and the telemeter receiving recorders at the various generating stations are designed as the Master control receivers. These channels constitute the links between the Chattanooga dispatchers' office and the regulating stations and on the basis of these readings the generation at the regulating stations will be varied automatically by the load frequency control equipment. Obviously the control will operate properly only when sufficient range of regulating capacity is available at the stations. Consequently, the station output of each of the principal regulating stations is telemetered back to the Chattanooga dispatcher, so that he will know at all times exactly how much regulating capacity is available at the regulating plant.

Type of automatic control.—Under normal operating conditions, the automatic load frequency control at each regulating station obtains its intelligence from the deviation-from-schedule reading as transmitted from the dispatcher's office and changes the

generation at the plant to assist in maintaining the average value of the deviation from schedule at zero. By sending deviation-from-schedule readings, it is possible to use instrument scales with wide deflection for small load changes, thus obtaining much closer regulation. This is accomplished by sending "raise" and "lower" control impulses to the synchronizing motor on each turbine governor. While operating in this manner, the governors still perform their all important task of protecting the units against overspeed in case of fault conditions.

With the control equipment, provided at each station, any one of the following types of automatic operation can be placed in service by means of selector switches. In all cases, the operation at the various generating stations depends upon the instructions received from the load dispatcher's office.

Flat tie line load control permits maintaining a scheduled power transfer on a tie line regardless of frequency which is then controlled by one of the systems on the opposite side of the tie line from the tie line regulating station. This type of operation assures the delivery of a scheduled amount of power over the tie line by increasing or decreasing the generation at the regulating station to maintain the scheduled interchange. This interchange may flow over a single tie line or may consist of the net flow over several ties and may be either metered locally or telemetered from the load dispatcher's office. This type of control was used extensively in the early days of the T.V.A. operation.

When flat tie line load control is used, one of the systems on the opposite side of the tie line from the tie line regulating station must maintain the system frequency. If this frequency is closely controlled, it is a relatively easy matter to hold a constant power flow towards that system. This is specially true, if the installed capacity on the side of the line containing the regulating station is small. However, when large amounts of installed capacity exist on each side of the tie line, since very little more regulating effort is required by tie line load bias control and assistance can be given to maintaining frequency, flat tie line load control is rarely used, but bias control is used instead. As tie system frequency varies, regulation is required to correct not only for changes in area load, but also for tie line load swings caused by the frequency variations. In fact, much of this regulating effort actually opposes system frequency and makes the operating problem worse. Flat tie line control must be used occasionally, however, when loads near tie line capacity loads are scheduled, as additional loading which may be caused by the frequency bias control might overload the line or lines and result in system instability.

Tie line load bias control permits maintaining a scheduled power transfer on a tie line, but the scheduled value in megawatts applies only when the system frequency is exactly at 60 cycles. At any other frequency, the tie line control point is offset in a direction to restore the frequency to 60 cycles at a rate determined by the bias. The bias is the shift in the tie line control point with frequency variation and is specified in megawatts per 0·1 cycle of frequency change. The equipment is arranged to control a single tie line or the net of several ties, either metered locally or telemetered from the Chattanooga dispatching office.

Selective frequency control is a type of tie line control which was used extensively before the tie line load bias control was widely accepted as the correct way to operate all large systems. This type of control was used to regulate for load changes occurring on one system but not for those originating on another system.

This is unlike flat tie line load control where all tie connections are made to maintain the scheduled interchange regardless of where the load swing originated. With selective frequency control, the primary response was from frequency and assistance was given to the frequency regulating system, provided the change in generation required was in a direction

to maintain the interchange on the tie line to that system. It did not connect the frequency dispatchers when the change in generation caused the interchange to deviate further from the schedule.

On extremely large inter-connections, the normal load changes are not large enough to cause an appreciable change in system frequency and in the development of inter-connected system operating practice, it was soon realized that the primary control response should be from tie line load rather than frequency. Consequently, the use of selective frequency control is now confined to relatively small systems and is not normally employed as a type of automatic operation on the T.V.A. system. For this reason, selective frequency control has been eliminated from the load frequency control equipment at most of the recent stations such as Watauga.

Flat frequency control will maintain the average system frequency at 60 cycles. Flat frequency control is used by the T.V.A. stations, during the periods when the T.V.A. system or a portion of it may be separated from the inter-connected system. High accuracy time standards are provided at several key stations so that system time can be maintained correctly during these periods of separation.

The time standard at Chickamauga at present serves as the master time standard for the T.V.A. system. The system time error reading as measured at Chickamauga by the time error indicator is telemetered to the Chattanooga load dispatcher's office where a record is kept of the system time error on an hourly basis. Two of the stations with time standard equipment are provided with facilities for daily checking against Airlington time signals.

Base load control maintains the output of each generating station at a predetermined scheduled value by means of the unit load controllers. Under normal operating conditions, all the main hydro units on the system are operated under base load control except those at the stations which are regulating the deviation-from-schedule reading telemetered from the load dispatcher's office.

Proportional load control permits the several generating units being used to regulate the deviation-from-schedule reading or any other condition selected by the dispatcher, to divide load equally among these units or to divide it on the basis of predetermined adjustable ratio. The trend is to have a large number of regulating units so that the burden on any one unit is small.

Condensing-Generating operation provides standby frequency control for generating units when operating as synchronous condensers which allows them to assist in the regulation of system frequency under emergency condition. When the system frequency drops below the predetermined value for a given length of time, the unit will automatically pick up generation until the system frequency is restored to 60 cycles. On the restoration of the frequency the unit can be retired manually to condenser operation.

The principal devices used at present for load frequency control are as follows :—

(i) *Time control equipment*—This consists of highly refined standard frequency sources which operate master clock and time error indicator. The time source at each of the 6 stations, Norris, Wheeler, Pickwick, Wilson, Guntersville and Chickamauga, consists of a tuning fork maintained at a constant temperature. The clock and tuning forks are accurate to within ± 0·75 seconds in 24 hours and the overall clock system has an accuracy of within ± 2 seconds in 24 hours. The tuning fork at Chickamauga is placed in a hermetically sealed tank.

(ii) *Load controller for each unit.*—This measures the generator output and controls it at the value set on the load setter. When the generating unit operates in a group with other units, this device keeps the load on each unit equal or proportional to that on the unit operating as master. The proportionality or ratio is adjustable.

(iii) *Station Load Recorder.*—It has a setter for limiting the regulating range of the station.

(iv) *Frequency Recorder.*—This contains a setter to set the frequency under flat frequency control and a bias setter for use under tie line load bias control. The bias dial is calibrated directly in Megawatts per 0·1 cycle frequency change.

(v) *Tie Line Load Recorder.*

(vi) *A master load frequency controller.*

Automatic load frequency control.—Each generating station is provided with an automatic load frequency control equipment which includes a unit load controller for each generator, a station load recorder, a tie line load recorder, controller, a master load frequency controller, a time error indicator and associated switches and auxiliary devices. This equipment provides (i) base load control on any or all generators, (ii) proportionate load control between units, (iii) flat frequency control on part or all of the transmission system, (iv) flat tie line load control, (v) tie line load biased frequency control, (vi) selective frequency control, (vii) condenser operation as standby spinning capacity.

This accomplishes any of the following operating conditions within the limits of the stations generating capacity :

(1) maintain a predetermined load on a selected tie line.

(2) maintain a constant output and station base load.

(3) maintain a predetermined load on each generator.

(4) maintain high and low frequency limits to trip the load control when limits are exceeded during system trouble.

Two (6 element automatic) Oscillographs are located on the switchboard for recording transmission line faults and for checking the performance of protective relays ; current and potential circuits are connected to the Oscillograph through plug and block arrangements mounted behind the panel to facilitate the selection of any line at will.

Tennessee Valley Authority Specifications for standard frequency source, load and frequency controls and temperature recorder for power plant.—The standard frequency source shall consist of a tuning fork, a motor generator set, two 6-inch master clocks, one 6-inch station clock, two 6-inch time error indicators, etc., for the operation of a 2,000 watt. supply station clocks, recorders.

One of the most important system requirements consists of maintaining scheduled loads over the tie lines to other systems. The loads over the inter-connections must be maintained within contract limits. No more than one tie line will be controlled at one time, when all generators are operating on the same bus. The station may be called upon to regulate the frequency or to assist in regulating the frequency and may also be called upon to maintain a scheduled base load.

The load and frequency control shall include all necessary apparatus for the automatic control of the generating units of the station to accomplish any one of the following conditions of operation with the degree of sensitivity and within the guaranteed accuracies of measurement specified for each operation:—

(1) Hold on each generating unit a fixed load, adjustable at will, in order to permit the station to operate as two independent stations. Overall sensitivity of load measurement shall be within $\frac{1}{2}$ per cent and guaranteed overall accuracy of load measurement shall be within $1\frac{1}{2}$ per cent.

(2) Maintain a fixed output or station base load by means of unit control for regulating stream flow or other system conditions.

(3) Regulate the system frequency at 60 cycle with an instantaneous sensitivity of measurement within 0·005 of a cycle and a guaranteed accuracy of measurement within 0·025 of a cycle instantaneous, to effect satisfactory operation within the load change capacity of the generating units under control,

(4) The load changes originating in its particular area is absorbed within the limits of the generating capacity under control so as to minimise unnecessary power transfer over the lines ; sensitivity and accuracy as above specified.

(5) Maintain a selected tie line load within predetermined adjustable KW limits without exceeding the capacities of the generating units under control.

(6) Permit the operation of one or more generators as synchronous condensers with automatic control for picking up load in case of tie line failure.

In order to provide for operation of the station as two independent stations provision shall be made for placing each generator on the following types of automatic control regardless of the type of operation chosen for the remaining generators.

(*a*) Adjustable proportionate load control.

(*b*) Independent base load control.

Automatic base load control for any unit or units shall be available regardless of whether or not the master frequency regulator is in service and adjustable means shall be provided for selecting any desired base load. Provision shall be made for individual manual adjustment of the load to be automatically maintained in each generator. Selector switches or equivalent shall be provided for placing individual units under control. The contractor shall also include provision for transferring the station master control equipment to any generator.

A station selector switch or the equivalent shall be provided for manually setting the station control under any one of the conditions outlined above or on manual control. This switch shall indicate under which type of control the station is operating. The control equipment for this station shall permit the station to operate satisfactorily in parallel with other plants on the same transmission system.

The equipment includes—

(i) frequency controller,

(ii) unit load controller,

(iii) frequency and time error recorder with minute impulse device,

(iv) station load recorder for totalising the load on the generators, and

(v) tie line recorder-controller.

Safety features shall be provided to disconnect automatically the load and frequency equipment and restore the station to manual control, making it necessary to restore the station manually to automatic control under the following conditions :—

(1) When the frequency varies by more than an amount predetermined, by adjustable contacts on the frequency recorder.

(2) When the A.C. voltage fails or the D.C. voltage drops down to approximately 80 per cent of normal.

5. Bureau of Reclamation.

5.1. *Layout of plants*—(i) *Location of plants*.—Most of the hydro-electric plants owned and operated by the Bureau are designed for location at or immediately adjacent to a dam, utilizing only that head developed by the dam. Some plants are however designed for locations remote from a dam such as at the lower end of a pressure penstock, power tunnel, power canal and at a drop in an irrigation canal.

(ii) *Types of plants*.—The plants are of the indoor or outdoor type. In the former type, mostly all the equipments including overhead crane are completely housed. However, at some indoor plants all power plant machinery is housed except the gantry crane which serves the generating units through hatches with removable covers. In the case of outdoor plants, a part of the power plant equipment such as generators (with weather proof housings) and gantry crane is not protected by a building. Determination of the type of structure to be adopted for a particular location involves studies of climatic conditions, structural considerations, earthquake factors, flood hazards and economic considerations.

(iii) *Location of equipments*.—After deciding the general location of a power plant building in combination with the associated structures of the project, further study is devoted to the location of the separate items of equipments such as transformers, circuit breakers and lightning arresters. In general, when the generating units exceed 30 MVA capacity each, the transformers and high voltage lightning arresters are located at the power plant structure. When the generating units are less than 30,000 KVA capacity each, this practice is not followed since generator voltage connections to the step-up transformers are relatively small and can be made long without requiring much additional expensive power house space for the leads or expensive heavy conductors, and hence the transformers may be located on the power house building or in a separate switchyard or in an intermediate location. The lightning arresters are located as near as possible to the transformers which are to be protected by them. The electrical equipment, viz., generator and exciter cubicles should be preferably located close to the generator room so that the cable connections will be short and also from the point of view of operating convenience.

(iv) *Location of control room*.—Visual observation of the generators by the operator is no longer a consideration in locating the control room. However it is preferable to have the control room in a central location with respect to the switchyard and generator room in order to have short control cables and also for operating reasons. In large power plants, a great number of control cables come in from the generator room, electrical bay and switchyard for control, protection, metering, communication and annunciation. They are usually spaced beneath the control room floor and connected to their respective panels. The operator's desk is equipped with a telephone turret allowing communication with the load dispatcher, other stations of the system and local power house telephones. In very small stations the control room is placed in the generator room to save construction and operating costs. In some modern stations the control systems are remotely operated from places located miles away. Such plants are usually equipped with a duplicate manually operated control board at the plant for use in case of emergency.

(v) *Location of Auxiliary equipment*.—Generator auxiliary equipment such as exciter cubicles should be preferably placed adjacent to the generator room especially for the unit type of design. This is also true of the unit auxiliary boards serving their corresponding generators. The pipe gallery for oil, water and air piping is preferably placed between the generator floor and the turbine floor with its mechanical equipment located either adjoining the generator room or in the service bay under the assembly space at the end of the generator room, as space permits.

(vi) *Location of switchyard*.—The location of the switchyard depends upon the topography of the site. A level space near the power house is preferred. If only hilly

ground is available with limited level space, the switchyard may be designed to use terraced levels and relatively tall structures. Sometimes the power house roof has been used as a switchyard. This is undesirable as it may restrict future expansion.

(vii) *Location of fire protection.*—The CO_2 fire protection is placed as close as possible to the generators or the equipment which is to be protected.

(viii) *Cables.*—The main control cable paths lead to the control room, one from the power house and the other from the switchyard. The cables from the power house are generally supported on cable trays which allow easy access for repair and simplify rerouting, Control cables from the switchyard are in ducts or cable tunnels and trays are employed depending upon the size and importance of the station and the number of cables involved. All control cables come to spreading room trays for rearrangement before being connected to their corresponding control panels. In some power plants, terminal rooms, between the floor of the control room and the spreading room, are provided.

(ix) *Other aspects.*—Large stations usually have a service bay at the unloading and entrance end of the plant the top floor of which provides unloading and setting down space for incoming equipment. The lower floors of this bay provide room and space for housing miscellaneous auxiliary equipment such as mechanical and servicing equipment that can be located away from the generating units. This includes oil storage and purification equipment, oil pumps, sump pumps, raw water system, filter plants and air compressors.

A power house located at the top of a high head dam may have its service galleries placed between the dam and the generator room while the power house of long penstock design sometimes has its service galleries placed on the intake side.

Summarizing the principal features of a typical power plant building and the items of equipment which they house or accommodate, are as follows :—

I. Generator room—

(1) Generators and exciters.

(2) Crane.

(3) Assembling and loading space.

II. Turbine room—

(1) Turbines.

(2) Governor and accessories.

(3) Unit control board including turbine operating board, exciter cubicles and auxiliary power boards.

(4) Station service generator and control equipment if provided.

(5) Turbine operator's desk.

III. Control room—

(1) Switch boards.

(2) Operator's desk with telephone communication facilities and annunciation signals.

IV. Service bay—

(1) Generator electrical accessories, OCB's, PT's, CT's and neutral grounding cubicles.

(2) Station service transformer.

(3) Storage battery.

(4) Cooling water system.

(5) Governor and lubricating oil system.

(6) Compressed air system.

(7) CO_2 for fire extinguishing system.

5.2. *Drainage systems.*—A gravity drainage system ordinarily drains waste water to a sump from which it is pumped to the tail-race. The system includes floor drains, drains for compressor cooling water, and drains for other discharges often intermittent in character.

Each drainage sump should have sufficient volume to permit a minimum of three minutes running of the sump pump during each cycle of operation. Experience has shown that one gallon per minute seepage may be expected through 300 square feet of submerged wall. Two sump pumps are preferred each of a capacity of at least 150 per cent of the seepage. Deep well type pumps with the motor above the maximum tail water level are used. Flood controls cause the selected pump to operate as required, with the second pump cutting-in if the first fails to handle the inflow.

The general principles of design are—

(1) All walls in contact with water should have drainage trenches along their interior faces, with suitable floor drains.

(2) Oil storage and purifier rooms should have chilling drains, with gravel pockets, of sufficient capacity to carry the flow from the sprinkler system.

(3) All embedded pipe in the drainage system should be extra heavy cast-iron pipe with long sweeps at all horizontal turns. Horizontal lines should slope one-fourth inch to the foot if practicable, with a minimum of one-eighth inch to the foot. No drain line should be less than four inches in diameter except short drain lines. It should have sharply sloped runs with few bends from sinks or small pits. Short drain lines may be of two inches in diameter.

(4) Drain lines to a main drainage header or sump should be trapped by bell-trap drains to prevent escape of odours. The discharge into the sump should be below the low-water level to reduce noise. Vertical drains discharging into floor drain on lower floors need not be trapped.

(5) Drains from the battery room floor and sink should be acid-resistant. Lines should slope a minimum of one-fourth inch to the foot, have no pockets, or traps, and should discharge directly into the sump or tail-race.

(6) Where embedded pipes cross expansion or contraction joints, a hub caulked with oakum, but not leaded should be installed in the plane of the joint. This will permit minor movements without damage. Pipes crossing construction joints between first and second stage concrete should have a hub flush with the first stage concrete to prevent damage during erection. Floor drains projecting above the subfloor should be installed when the floor finish is laid.

Pressure drainage.—This comprises the drainage of the cooling water from the bearings, generator and transformer coolers, to an outlet below the normal tail water level. This system is subject to the pressure of tail water plus the losses and is designed to run full at all times. The dewatering system is a pressure system for dewatering the turbine case, draft tube, etc., and discharge into a dewatering sump.

Two dewatering pumps similar to the drainage sump pumps are desirable. The sump size and float control should be designed for 3 minutes running time per cycle. The inflow is determined by the size of the dewatering line from either the turbine case or the draft-tube whichever is higher.

The turbine case drain line should be designed to dewater the case from the centre line of the distributor to the invert, including head gate leakage, in less than 30 minutes. One-tenth of 1 per cent of the rated turbine discharge should be allowed for head gate leakage.

Each draft tube drain line under normal tail water should discharge not less than one half of 1 per cent of the rated turbine discharge, to aid in sealing the draft tube bulk head gates. This line should be capable of removing one tenth of 1 per cent of the rated turbine discharge and leakage through the draft tube bulk head gates after sealing, with the water level at the floor of the tube.

The dewatering sump may act as a reserve drainage sump in case of accidents or flood and it should be provided with automatic float controls similar to those of the drainage sump. In small plants, the dewatering sump may be connected with the drainage sump pump or provision may be made for the use of portable pumps.

Drainage system of Hungry Horse Dam.—The power plant building is drained by 3 headers, a service bay header, an upstream header, and a downstream header. These headers are combined to form a 14-inch main that discharges into a sump constructed under the service bay. The sump has a capacity of 4,000 gallons per foot of depth. If need arises, the discharge may be diverted from the drainage sump into the adjoining dewatering sump by closing the 14 inches drainage sump shut-off valve. The drainage system provides drainage for all floors in contact with the down stream face of the dam and also for all floors and galleries in the remainder of the power plant. This provides for any seepage that may occur through the dam or though the outside submerged walls of the power plant below an elevation corresponding to the high tail water level. The turbine pits, elevator pit, filter washing trays, air compressor cooling water and the formed drains in the building expansion joints also drain into this system. The generator housings are drained into the turbine pits through relief valves designed to prevent the escape of CO_2 gas from the housing.

The drainage sump is provided with 2 Nos. 900 gallons per minute 29 at feet head, 10 h.p. deep-well turbine pumps, one 4 inches eductor 100 gallons per minute suction capacity, 30 feet discharge head and one adjustable float switch.

The automatic float operated switch, provides start and stop control for the pumps and eductor ; it also sounds an alarm upon the occurrence of a high water level in the sump. The eductor may also be used to completely unwater the sump when necessary. Normal drainage not exceeding 100 gallons per minute will be automatically handled by the eductor.

5.3. *Hungry Horse Dam.*—The storage of the dam is 350,000 acre feet. Power is generated at 60 cycles by four generators of capacity of 75,000 KVA each, the generation voltage being 13·8 KV. The generators are driven by turbines of capacity of 105,000 h.p. which is controlled and regulated by a 5 inch, 200,000 ft. lb. oil pressure actuator governor. The effective head available at this plant varies between 260 to 484 feet with an average of 445 feet. The generators are bussed together in pairs, each pair of generators being connected to a bank of 3 Nos. 230 KV single phase transformers, one 115 KV three phase transformer and one three phase station service transformer.

The generator breakers are of the air blast type pneumatically operated and electrically controlled. The bus structure at this plant is of metal construction. The enclosure is formed into hollow square from aluminium sheets.

5.4. *Davis Dam Project—Tie line load and frequency control.*—The output of any number of the units at Davis can be controlled automatically by the load and frequency control system. This regulation of course is only effective to the extent that with a given setting of the controls, the possible range of output of the machines involved is adequate to maintain the set condition. However, if the units under control are unable to maintain the desired load or frequency the automatic controls will be de-energized and the units will return to

normal operation under the control of their individual governors. Since the plant will ordinarily be operated as part of a large interconnected system, the controls to be used, will be determined by the system dispatcher.

The equipment at Davis provides for the following four types of control (only one can be used at a time) :—

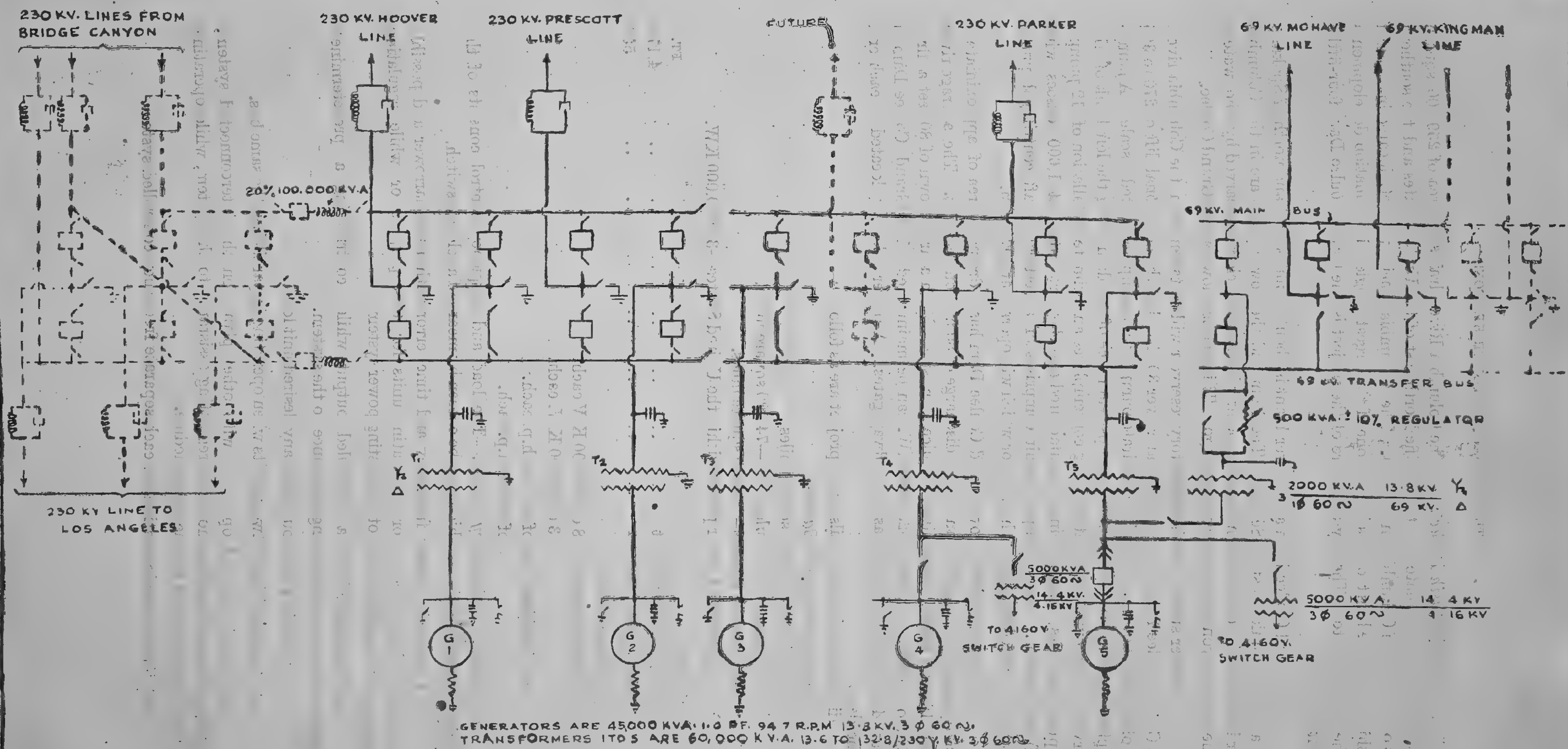
(1) A flat frequency control which will maintain a definite system frequency.

(2) A frequency time error control that ordinarily maintains a definite frequency but varies this slightly as required to limit the maximum time (difference between synchronous clock and correct time) to a maximum of few seconds.

(3) A flat tie line control that maintains a constant total load for all controlled 230 KV lines. This regulation will maintain a constant plant output at Davis of all the transmission lines in service under control.

(4) A tie line bias control that normally provides a flat tie line control similar to (3) but varies its control point slightly as required to help reduce frequency time error of the system. This will assist the master or frequency control plant of the net work.

The electrical layout of the station is given in Sketch P.S. 36.



LAY-OUT OF DAVIS DAM POWER PLANT

(BUREAU OF RECLAMATION)

SKETCH P.S. 36.

5.5. *Columbia Basin Project.*—(i) The Columbia River drains an area of 259,000 square miles basin and is situated in the Pacific Northwest of the United States and the southern part of the British Columbia in Canada. The Columbia basin project, located in Central Washington in the heart of this basin is one of the largest single Reclamation developments in the United States. The key structure of the project is the Grand Coulee Dam four-fifths of a mile long.

The Grand Coulee Dam and Power Plant is about 90 miles west and north of Spokane and about 240 miles east of Seattle. The Dam and the power plant are in the Columbia river immediately downstream from the point where a great cleft was carved by the waters in the river canyon south wall centuries ago. This cleft is known as the Grand Coulee.

The water supply for the regulatory reservoir will be taken from the Columbia river. The Grand Coulee Dam will raise the water over 300 feet but the additional lift of 270 to 365 feet of the high flow required will necessitate pumping at an unprecedented scale. A pumping plant is being built adjacent to the upstream face of the dam along the left bank of the reservoir. The pumping plant building contemplates an ultimate installation of 12 pumps. Six pumping units are now being manufactured and they are rated at 1,600 cusecs with a lift of 295 feet. Each pumping unit comprises of a vertical shaft centrifugal pump directly connected to a 65,000 h.p. motor which will operate at 200 r.p.m.

The Columbia river above Grand Coulee Dam has a drainage area of approximately 79,000 square miles and has an annual discharge of 80 million acre feet. The average river flow is 100,000 cusecs at the Grand Coulee Dam site. With a draw down of 80 feet a firm continuous power output of 925,000 K.W. can be maintained. The Grand Coulee Dam is about 4,200 feet long and has 11 spillway gates. A power plant is located at each end of the dam.

(ii) The statistical details of the project are as follows :—

(*a*) *Columbia River Basin*—

(1) Area—259,000 square miles.

(2) Area above Coulee dam—74,100 square miles.

(3) Area in Canada—39,700 square miles.

(4) Potential water power within the United States—30,000,000 KW.

(*b*) *Dam*—

	FT.
(1) Length of crest	4,173
(2) Spillway width	550

(*c*) *Power plant*—

(1) Generators—18 of 108,000 KW each.
3 of 10,000 KW. each.

(2) Turbines—18 of 165,000 h.p. each.
3 of 14,000 h.p. each.

(iii) *Load and frequency control.*—The load and frequency control consists of the following operating features which may be chosen by means of a selector switch.

(1) Maintain system frequency and time error within the narrower and possible limits while using one or more generating units for this purpose or while regulating co-operatively in parallel with other existing power systems.

(2) Operate about a scheduled output while contributing a predetermined adjustable amount of regulating assistance to the system.

(3) Maintain a fixed output at any desired unit load.

(4) Load division between units when operating in parallel on the same bus.

(5) Permit parallel operation with other plants on the interconnected system, contributing an adjustable amount of regulating assistance to the system, while operating about the predetermined tie line load schedule.

(6) Time error indication for each separate frequency controlled system.

5.6. *Pole Hill Power Plant.* —All water for driving the turbine will be diverted from the Estes lake by gravity canal, conduit, and tunnel and carried for a distance of about 10 miles before entering the penstock. Gates will be provided at the upper end of the penstock, for emergency and servicing purposes. Approximately 600 cusecs of water will be conducted to the turbine through a plate steel penstock 96 inches in diameter and 2,000 feet in length. The intake to the penstock will be from an open canal forebay at the lower end of the Pole Hill tunnel. Tail water will pass through a small after-bay to a pressure tunnel, 8,750 feet long and will discharge into Rattle snake reservoir, which has an active storage capacity of 1,400 acre feet. The head available is 815 feet and the capacity of the generator is 31,250 KVA (0.9 P.F.) which is driven by a 47,500 h.p. turbine.

Load control can be effected at the plant itself or by remote control from the Flat Iron power plant situated 5 miles away.

5.7. *Flat Iron Power Plant.*—This will be situated approximately 5 miles east of the Pole Hill Power Plant site. All water for driving the turbines will be diverted from Rattle-snake reservoir through a pressure tunnel 6,150 feet in length and plate steel penstock approximately, 72 inches in diameter and 5,550 feet in length. The pressure tunnel will connect directly to the intake end of the penstocks where the surge tank and penstock valves will be located.

The forebay of the Power plant will be formed by the Rattlesnake reservoir, below the Pole Hill Power Plant, and will provide a daily normal regulation of 400 acre feet of storage, which will provide for the plant, peak capacity of approximately 63,000 KW.

5.8. *Green Mountain Power Plant.*—Power is generated at 60 cycles by two generators of 12,000 KVA. capacity each and the generation voltage is 6·9 KV. The generators are connected to three single phase transformer banks of 4,000 KVA. and 8,000 KVA respectively.

6. British Electricity Authority.

6.1. *Technical characteristics.*—The following tables give the technical characteristics of the generating stations in Great Britain :—

(a) *Some of the steam stations.*

Plant.	Number and size of turbo-generators M.W.	Number and size of Boilers lb./hr.	Steam pressure lb./sq. inch.	Steam temperature. °F
1 Littlebrook 'A'	2-30 and 1-60	6-256,000	600	800
2 Littlebrook 'B'	2-60	4-265,000	1,235	825
3 Littlebrook 'C'	4-60	7-360,000	900	900
4 Cliff Quay	4-45	9-365,000	600	825
5 Hams Hall 'B'	6-53·5	12-320,000	650	825
6 Staythorpe	6-60	18-240,000	900	900
7 Ferrybridge 'A'	2-20	8-57,000	300	675
8 Doncaster	4-30	8-180,000	600	850
9 Dunston 'B'	6-50	8-135,000 2-410,000	600	850
10 Kearsely 'A'	2-31·25	8-95,000	300	675
'B'	2-51·6			
'C'	2-52	16-160,000	600	800
11 Bromborough	4-50	8-300,000	900	900
12 Partishead	3-60	6-300,000	900	900

(b) Hydro-Electric Station.

	Size and number.	Head.
		FEET
Pitlochry—North of Scotland Board ..	2-7·5 M.W.	50
Loch Sloy—North of Scotland Board ..	4-32·5 M.W.	910
Tummel Bridge—North of Scotland Board ..	3-25 M.W.	553
Errochty—North of Scotland Board ..	3-25 M.W.	610
Clunie—North of Scotland Board ..	3-20·4 M.W.	173
Maentwrog—Merseyside and North Wales ..	2-12 M.W.	650

Number of steam stations with an installed capacity of over 100 M.W. ..	53
Number of steam stations with an installed capacity of 10-99 M.W. ..	106
Number of steam stations with an installed capacity of under 10 M.W. ..	130

The average plant size is 44 M.W.

The hydro plant installations, nearly all in Scotland and Wales represent less than 2 per cent of the total capacity. Even though there is heavy rainfall, more power cannot be generated on account of the smaller catch basins.

Typically, the British Hydro plants are used for peaking purposes only and operate at 10 to 20 per cent annual use factor.

The B.E.A. records of generating plant capacity and output are based on the maximum continuous rating of each main item of the plant at each generating station in the following three essential categories :—

(a) Generating sets.

(b) Boilers.

(c) Cooling equipment.

6.2. *Thermal efficiency.*—The maximum probable thermal efficiencies to be expected from the stations in the lower pressure group assuming that they were operated at 80 per cent load factor would be between 16·15 per cent and 21·85 per cent approximately.

In the higher pressure group, operating between 300 and 600 lb./sq.in. the corresponding figure would be in the order of 21·85 to 26·6 per cent.

Thermal efficiency of some of the generating stations in England.

Power Station.	Steam pressure at turbine stop valve. lb. per sq. inch.	Steam temperature degrees Fahrenheit.	Average load as a percentage of maximum output capacity.	Calorific value of fuel—B.T.U. per lb.	Fuel burnt per unit sent out.	Thermal efficiency.
					LB.	PER CENT.
Dunston	600	850	79	11,154	1·034	29·59
Littlebrook	1,235	825	57	11,163	1·043	29·31
Stourport	1,250	950	62	10,999	1·082	28·67
Battersea	1,350	950	62	12,763	0·936	28·55
Cliff Quay	600	825	74	11,298	1·124	26·86
Fulham	600	800	71	12,589	1·012	26·78
Staythorpe	900	400	59	10,324	1·259	26·24
Meaford	600	825	86	11,243	1·179	25·73
Kearsley	600	800	72	10,931	1·218	25·63
Mean value	..	..	47	10,928	1·417	22·04

In assessing the order of merit of the generating plant in each area and the incremental fuel costs of area generation, the cost of heat shall be calculated from the following formula :—

$$\text{Cost of heat in d/10,000 B.T.U.} = \frac{\text{Inclusive fuel cost per ton (pence)} \times 10{,}000}{2{,}240 \times \text{Calorific value in B.T.U.}}$$

Inclusive fuel cost per ton shall be the average price per ton of fuel delivered at site, with the addition of the average cost of fuel handling per ton for the last 12 months. Calorific value shall be the average gross calorific value of the fuel delivered to site for the last three months.

6.3. *Fuel consumed, ash discharged, etc. (estimated quantities).*—

A Power Station in B.E.A.

Plant in Operation.	*Load. factor*	*Fuel per hour.*	*Fuel per day in tons.*	*Ash/hr, tons.*	*Ash/ day tons.*	*Capacity of slurry pits in days.* No. 1 pit.	No. 2 pit.	No. 3 pit.	No. 4 pit.
	PER CENT.	TONS.							
30 MW. No. 1	70	15·8	265·5	3·95	66·375	132	188	169	121
60 MW. No. 1	70	31·6	531·0	7·9	132·75	66	94	84	60
90 MW. Nos. 1 and 2	70	47·5	797·0	11·875	199·25	44	62	56	40

Fuel consumption—1·18 lb./KWH.

Ash discharged—0·295 lb. per KWH.

Weight of Pulverised Fuel ash—50 cubic feet/ton.

No. 1, slurry pit capacity—440,450 cubic feet or 8,809 tons.

No. 2 slurry pit capacity—626,100 cubic feet or 12,522 tons.

No. 3 slurry pit capacity—564,650 cubic feet or 11,293 tons.

No. 4 slurry pit capacity—402,100 cubic feet or 8,042 tons.

Calorific value—9,300 B.T.U./lb.

Fuel—1½ inches dry slack.

Total moisture—10 per cent.

Ash content—25 per cent.

6.4. *Boilers (General).*—

(i) Continuous maximum rating—300,000 lb./hr.

Superheater outlet at C.M.R.—625 lb./sq.in.

Superheater outlet temperature at C.M.R.—865°F.

Temperature control range 80 to 100 per cent C.M.R.

Feed temperature at economizer inlet at C.M.R.—345°F.

Power supply—3·3 KV. and 415 V. 3 phase 50 cycles—240 V. single phase and 240 V. D.C.

Type—Pulverized fuel fired and natural circulation water tube type.

The unit shall be capable of steaming at the maximum output with one pulverizer out of service when burning the coal specified.

150,000 lb./hr. Locks Twin travelling grate stoker fired.

(ii) *Soot blower system.*—Each boiler has 18 hydraulically operated soot blowers arranged for automatic sequence control.

The control permits selection of the following methods of operation :—

(1) Through the full sequence automatically.

(2) With the suppression of any pre-selected blowers from the full sequence.

(3) Any selected blower individually.

In addition the pre-selected sequence can be interrupted at any point and re-set.

If during the sequence of operation a head fails to complete its operation in a predetermined time, operation of all heads is stopped automatically and an alarm sounds.

The soot blowers can also be operated manually. Steam at full boiler pressure (tapped off the primary superheater outlet pipe) is used and the reduced pressures at the various blowers are obtained by means of the plates.

Blower numbers.	Type.	Location.	Pressure. LB. PER. SQ. I .
1–3	B. & W. Retractable single nozzle.	Furnace rear walls ..	425
4–6	Do.	Furnace front walls ..	350
7–12	Do.	Superheater	350
13–14	B. & W. Pilot valve mass element.	Boiler side walls	350
15–18	Babcock and Howden ..	Airheater	250–280

(iii) *Motors for Boiler Feed Pumps, etc.*—The motors for the boiler feed pumps are operated at a voltage of 3,300 V. with their neutrals solidly earthed.

The starting current at full load voltage must not exceed six times the full load current.

All motors shall be suitable for starting at full voltage direct on to the line, without star-delta or auto transformer starters.

The motors should be capable of providing continually the maximum torque demanded by the drive when the voltage varies between 10 per cent below and 15 per cent above the normal with or without a reduction in frequency to 48 cycles per second.

Motors up to and including 150 h.p. are of 415 V. 3 phase and motors above 150 h.p. are rated for a nominal supply of 3·3 KV. 3 phase 50 cycles.

Motors operating in an ambient temperature of 104°F (40°C) shall be insulated with class A insulation but when the ambient temperature is likely to exceed this figure, the motors shall have Class B insulation.

Chimney stacks.—An architectural feature of the new plants in British practice has been the use of only one or two high masonry stack for the whole station. Also as a rule, 2½ times building height has been adopted, leading to stack heights of 350 to 400 feet. In American practice about 300 feet is the average height for the chimney.

6·5. *Carrington Power Station.*—(i) *General.*—This station will have initially two generating sets of 60 M.W. capacity each and the generation voltage is 11 KV. The generators are being connected to a 11/132 KV. step up transformer, all switching being done at 132 KV.

Auxiliary supplies will be obtained from unit transformers 5 MVA. 11 KV/3·3 KV solidly connected to each generator and also from two station transformers 10 MVA. 132 KV./3·3 KV.

(ii) *Control room.*—The control room is equipped with a control board, generator desks, operator's desk, voltage regulator board, etc. The relay boards and alarm annunciator racks will be placed in the adjacent room.

All controls are being done at 110 volts D.C. and all indication of circuit breaker, isolator positions, etc., at 50 volts D.C.

A non-interlocked synchronising scheme will be provided. Phase to earth voltage is used throughout, the necessary voltage transformers being on the yellow phase.

(iii) *M. V. Turbo-alternator sets*—60 *M.W.*—

(1) Steam pressure at T.S.V.—900 lb./sq. in.

(2) Steam temperature—900° F.

(3) Cooling water temperature—70° F.

(4) Exhaust pressure (absolute) at turbine exhaust flanges—1·4 inches of mercury at generator's maximum continuous load.

(5) Speed—3,000 R.P.M.

(6) Governor—The variation in angular velocity during each revolution must not exceed 1/20 of 1 per cent with constant load.

(7) Oil system.—Each turbine is equipped with a complete system of forced lubrication for its bearings and those of the generators and exciters and have

(*a*) a direct driven pump capable of maintaining a constant pressure of not less than 10 P.S.I. at the bearings, also a full duty standby oil pump driven by an A.C. motor; the pumps must be capable of maintaining sufficient pressure to operate the governor gear relay system and

(*b*) an electrically driven jacking pump.

Arrangements to be made for automatically starting the stand-by pump when oil pressure is less than a pre-determined value and for starting the flushing pump when the oil pressure falls to a pre-determined lower value.

An interlock is to be provided to prevent the jacking pump being started until either the stand-by or the flushing pump is operating and oil is available for the jacking pump.

The pumps are to have separate strainers and are to draw from a baffled tank having a capacity of not less than eight minutes supply and designed to ensure high degree of deaeration and demulsification of oil.

The volume of entrained air in the oil at the entrance to the cooler shall not exceed 1 per cent of the volume of the oil. Two oil centrifuges to operate in series one at 11° F and the other at a temperature between 140 and 160°F are provided.

(iv) *Feed Water Heaters.*—Bleed Feed Water Heaters are used to raise the temperature of the condensate on 60 M.W. load to 365° F. The heater immediately before the boiler feed pump is to be of the deaerator type complete with condensate storage tank.

Reliable automatic means be provided to prevent water getting into the turbines, due to burst tube, leakage or other causes.

(v) *Evaporators.*—The capacity of the evaporators is 26,000 lb./hr. for each turbine. The live steam for the evaporators is to be taken from one of the feed heater tapping points on each turbine. The vapour should be returned to the feed heater supplied from the next lower tapping; the condensate must be passed through flash boxes to the condenser condensate.

An auxiliary ejector should be provided for each set to boost the extraction so that under normal conditions of starting, a vacuum of 22 inches can be obtained in three minutes.

(vi) *Make-up water.*—Make up water taken from the surge tank will be passed into the condenser for deaeration. The Oxygen content of the condensate shall not exceed 0·05 cc/litre.

(vii) *Lagging.*—All pipes, valves and surfaces having an internal temperature of over 500°F are to be lagged with two $2\frac{1}{2}$ inches thick layers of sectional 100 per cent amosite asbestos, secured with 19 SWG 1 inch mesh wire netting, supercoated with $\frac{1}{2}$ inch thick hard setting insulating cement, suitably reinforced ; plastic is to be used where necessary on account of the shapes of valves, etc.

High pressure drains are to be lagged with similar material two-third the thickness given above.

The low pressure steam pipes and the whole of the condensate system from the inlet of the first heater to the outlet of the last heater including the heaters, are to be lagged with $4\frac{1}{2}$ inches thickness of 85 per cent magnesia composition and $\frac{1}{2}$ inch wire reinforced hard setting composition.

The turbine casings are to be lagged with not less than 4 inches thick plastic amosite asbestos with a minimum quantity of keiselguhr, reinforced with two layers of netting and finished with a hard setting and insulating cement.

(viii) *Painting.*—The pipe works are to be finished with aluminium, and have coloured bands 3 inches wide 18 inches on either side of each flange joint as indicated below :—

High pressure steam pipes, etc.—Red.

Low pressure steam pipes, etc.—Green.

(ix) *Pipes.*—The following are the materials that are used for the various sections of the pipes. The pipes are specially selected to keep "creep" at a minimum when continually at a temperature of 930°F.

(1) The higher pressure steam pipes are of best quality weldless open acid or basic steel with neither sulphurnor phosphorous content exceeding 0·05 per cent.

(2) The medium pressure steam pipes are to be of best quality Siemens-Martin steel.

(3) The oil pipes are of steel.

(4) The balance and drain pipes between the feed water heaters are of copper.

(5) Bolts for high pressure parts must be of alloy steel, specially selected to keep creep at a minimum when continuously operating at a temperature of 900°F. Test sheets are to be provided to show that the resistance to creep when stressed at high temperature, are minimum and also to show the effect on the impact value after the material has been subjected to high temperature for long periods. The Izod impact value should not be less than 35 feet lb.

The test pressure for the pipes is to be in accordance with B.S.S. 806 but with a minimum of 50 lb./square inch (i.e. twice the working pressure, except, when twice working pressure is less than 50 lb. In such cases test pressure of 50 lb. is to be specified)

(x) *Jointing material.*—1/32 inch thick jointing material such as Klingerite is suitable for all services including oil, except for pipes carrying circulating water above 60° F. In general 1/16 inch thick rubber jointing is to be specified for circulating water pipes.

(xi) *Painting after erection.*—Pipes located outside the buildings and subject to weather are to be painted as follows :—

Primary coats : 3 coats of red lead ready mixed to B.S. 1011.

Finishing : Two coats of oil base paint.

(xii) *Oil pipes.*—Special attention is required for oil pipes and the following specification is used. Pipes are to be immersed in a pickling solution consisting of 85 parts of water to 15 parts of hydro-chloric acid by volume, for not less than 24 hours ; the scale is to be removed by brushing with a wire brush. The pipes should be then immersed in a lime solution, the bath of which should be agitated to prevent silting. When thoroughly dry the pipes should receive one coat of priming paint and finished with one coat of good quality oil paint on outside. No paint is required on the inside of pipes.

(xiii) *Condenser.*—The materials used for the manufacture of the condenser is usually the Admirality mixture of 70 per cent copper, 29 per cent zinc and one per cent tin.

(xiv) *Specifications for boilers.*—

(1) Pulverised fuel.

(2) *M.C.R.*—260,000 lb. of water per hr. when burning coal having a calorific value, as fired, of 10,000 B.Th. U. and supplied with feeder water at a temperature of 380° F.

(3) Steam pressure at the boiler stop valve outlet 900 lb. per square inch.

(4) Steam temperature variation at any load between 288,000 and 360,000 lb./hr. must not exceed 15° F below or above 920° F.

(5) Net overall efficiency is to be maximum at 0·8 of the maximum continuous rating. There shall be as little variation of efficiency as practicable between 0·65 and M.C.R.

(6) Safety valve is to lift out at a pressure equal to the sum of 940 lb. per square inch and the pressure drop between the steam drum and the boiler stop valve.

(7) The super-heaters must be of the self draining type forming integral portions of the boilers.

(8) The headers must be external to the boilers and the tubes must not be interleaved with boiler tubes.

(9) The boiler casings are to be of 3/16 inch thick steel plates for fire refractory material and lagging.

(10) *Electrostatic precipitators.*—Electrostatic type dust precipitating plant (preferably Lodge—Coltoll Company's make) is provided to remove grit and dust from the flue gases ; the amount left in the gas during ' soot ' blowing and the other periods must not exceed 0·4 of a grain per cubic foot of gas at N.T.P. No appreciable part of the dust remaining in the gas is to exceed 20 microns diameter.

The precipitators are on the boiler side of the induced draft fans.

The rate of flow of gas through the precipitators should be low, and care must be taken to ensure even distribution of gas over the collectors.

(11) *Forced draught and induced draught fans.*—There should be 2 forced draught and two induced draught fans per boiler.

The speed should not exceed 750 R.P.M. and the shaft should be designed so that the first critical speed is not less than 66·6 per cent above normal speed. These fans should have an excess capacity of 15 per cent when fuel as specified, is being used and CO_2 is as specified.

(12) *Motors.*—Motors must be capable of providing maximum torque required by the drive even when the voltage falls to 5 per cent below normal with or without reduction in frequency to 48 cycles per second. They must also remain stable if the system voltage falls to 66-2/3 per cent of normal with or without reduction of system frequency to 48 cycles per second for 10 minutes.

For all the draught fans, alternating current, 2 speed squirrel cage induction motors with starting current not exceeding 6 times full load current when started direct on the line are specified.

For the mills, A.C. single speed motor of squirrel cage type with starting current not exceeding 6 times full load current when started direct on the line and with starting torque not less than 2 times the full load torque are specified. All motors are to be totally enclosed, fan cooled or pipe ventilated.

(13) *Hydraulic tests.*—Before despatch to site, the drums and boilers should be tested to $1 \cdot 5 \times P$ plus 50 lb./square inch where P is the maximum permissible drum pressure. All steam blow down, drain and other pipes, valves and fittings subjected to the boiler pressure shall be tested before despatch to site, with a hydraulic pressure of twice maximum drum pressure. After erection they shall be tested with a hydraulic pressure equal to the actual working pressure.

All feed pipes, valves and fittings shall be tested before despatch to site with a hydraulic pressure of 2,700 lb./square inch. After erection, they shall be tested with hydraulic pressure equal to the actual working pressure.

All low pressure pipes shall be tested before despatch to site to 200 lb/square inch. The oil piping valves, bends, and fittings for the tighting up equipment shall be tested before despatch to site with a hydraulic pressure of 400 lb./square inch.

6.6. *Hartshead Generating Station.*—This generating station has 6 generators with 2 house sets. Three generators of 12,500 KW capacity each and a generator of 30,000 KW feed direct on to the 6·6 KV bus bars in the generating station. One generator of 30 MW. at 6·6 KV is connected through a step up transformer to 33 KV bars in the grid sub-station. The third set of 30 MW generates at 6·6 KV and feeds the 132 KV grid through step up transformers.

6.7. *Private Generating Plant.*—Because of the continued shortage of generating plant, some firms under contract to purchase the whole of their electricity requirements, have had under consideration the installation of private plant either as an insurance against load shedding, or to enable them to reduce during peak load periods to the extent required by the Regional loads for industry. Accordingly discussions have taken place from time to time between the Authority, the Area boards and the Federation of British Industries regarding the relaxation of restrictions in existing agreements in the use of private plant. During 1951-1952, the matter was further reviewed and as a result the Authority and Area boards have agreed to relax the restrictions until March 1959, subject to the terms and conditions of supply being adjusted to give the necessary financial and technical protection to the Boards.

The Authority do not consider that in general and as a long term policy, the installation of private plant is economic and in the national interest. Except in special cases, the installation and operation of such plant will make a greater call on labour and materials than a corresponding service from the public supply system.

Where however, process steam is required in factories, fuel economies may be effected by the installation of back pressure generating plant ; industrial installations of this special character may be economically justified when the process steam requirements are fairly substantial and where over the life of the plant a reasonable balance of the steam and the electricity requirements can be assured. In such cases, to obtain the most economical results suitable arrangements should be made for the operation of the plant in parallel with the public supply system and for the interchange of electricity supplies. The Boards are well aware of the part which back pressure plants can play in conserving coal and are fully prepared to co-operate with the industrialists willing to install them.

6.8. *Cables.*—(i) All cables and conductors which may have a voltage to earth exceeding 65 must be enclosed in a metallic sheath which is continuous and effectively earthed.

All cables and conductors which may have a voltage to earth exceeding 25 and not exceeding 65 shall, unless they are enclosed in a metalic sheath which is continuous and

effectively earthed, be covered with best quality tough rubber sheath. Three single core cables laid direct in the ground or in troughs forming one three phase circuit shall be laid close to one another in triangular formation and clamped together at frequent intervals. The relative position of the three cables shall be changed at each joint, complete transposition being effected in every three consecutive cable lengths.

Single cored lead covered A.C. cables are run in close trefoil formation so as to keep to a minimum sheath voltages and losses in the sheaths. With this arrangement, the cable sheaths are insulated from the switchgear or other apparatus at both ends and throughout the run bonded together and earthed at each final trefoil point. Cables run in this manner having a route length exceeding 30 yards shall in addition have the lead sheaths bonded together at intervals of approximately 30 yards. After the single cored cables leave the final trefoil points, the clamps must be carefully insulated.

The bonds employed shall have an equivalent copper sectional area of not less than 0·15 square inch and the combined resistance of the bond shall not be more than the combined resistance of an equal length of armouring and lead sheathing.

The bonding of lead sheath cables shall be of sheet lead 1/8 inch in thickness and approximately 4 inches wide wrapped round the trefoil cable assembly in such a manner as to make the maximum contact.

(ii) *Cable boxes.*—The cable boxes shall be fitted with universal tapered brass glands with combined armour and earthing clamp. Glands for single core cables shall be insulated from the box in an approved manner including an island layer and removable earthing connector shall be provided. Gland insulation shall be capable of withstanding a dry high voltage test of 2,000 V. A.C. for one minute on each side of the island layer.

Provision shall be made for earthing each cable box.

No insulated wire shall have less than three strands and each strand shall not be less than ·036 inch in diameter.

(iii) *Bonding and earthing of cable sheaths—I.*—In the installation of single core cables, it is essential to ensure that the bonding and earthing of the cable sheaths is carried out in such a manner as to safeguard equipment and personnel under all conditions. Owing to the diverse characteristics of cable installations, it is not practicable to specify a standard system of bonding and earthing. Each case must, therefore, receive individual consideration and the notes below give quantitative information on the effect of the various factors involved and make certain general recommendations.

Voltage and currents induced in sheaths.—The voltage to neutral induced in a single core cable sheath is given by—

$$Es = wMI = 2\pi fMI = 2 \times 50 \times \pi \times 0{\cdot}74 \quad \log \frac{D}{R} \times I \quad (\text{as} \quad M = 0.74 \quad \log \frac{D}{R} \ I, \ \text{mH}$$

per mile) or $Es = 23 \ \log \frac{D}{R}$ volts per mile per 100 amps, where M is the mutual inductance between core and sheath, D is the spacing between individual cables cores of a 3 phase system, R = mean radius of the cable sheath.

It is clear that considerable voltage may occur on long runs of cable with heavy load currents or under fault current conditions. As an indication of the magnitude of these voltages, it may be noted that if the spacing between cores is 3 times the sheath radius, the induced voltage is 11 volts/mile/per 100A. To limit the sheath potentials,

it is necessary to divide long lengths of cable into sections by insulating joints and sheath potentials should not exceed 10–15 V. The disadvantages of induced voltage are as follows :—

(*a*) Damage may occur under fault conditions due to arcing between sheaths.

(*b*) Danger to life may occur under normal operation and fault conditions.

(*c*) Corrosion of the cable sheath due to electrolysis may be accentuated.

The induced voltage may be eliminated by bonding the sheaths together at both ends of the cable. This procedure has the disadvantage that relatively heavy currents can flow in the sheaths. The value of the sheath current which is independent of the cable length is given by

$I_s = \frac{wMI}{R_s}$ where R_s is the resistance of the sheath.

Assuming the resistivity of the sheath as 24×10^{-6} ohm/cm³.

$$R_s = \frac{0{\cdot}2}{(R_2 - R_1)(R_2 + R_1)} \text{ ohm/mile}$$

where R_2 and R_1 are the external and internal radii of the sheath in inches.

The currents flowing in the sheath give rise to a power loss $P_s = I^2 R_s$ watts/per mile.

Sheath currents and losses increase rapidly with spacing and with conductor section. For large cables, the sheath current may be a considerable fraction of the load current, while the sheath losses may equal the load losses.

Sheath currents may therefore result in an appreciable reduction of the cable capacity, so that it is sometimes necessary to reduce or eliminate them.

Special methods of cross bonding have been developed in America, which neutralise the sheath current and limit the induced voltage.

It is usually sufficient from the stand-point of sheath losses to reduce the spacing to the minimum by laying the cables in a triangular formation with their sheaths in contact. The sheaths may then be bonded together and earthed at both ends. On long runs of cable in racks, bonding and earthing of the sheaths should also be carried out at intermediate points.

An important case is that in which large section cables diverge from the close triangular formation for connection to switchgear, transformers or overhead lines.

In this case, the spacing is inevitably increased but as the length involved is only a few yards, the induced voltage is low and the sheath currents can readily be prevented by means of insulating glands. The insulating glands may often spark over due to high transient voltages produced by switching or fault conditions or cause burning of the sheaths.

The insulating gland may therefore not be wholly a satisfactory solution in all cases and it may sometimes be necessary to earth the cable glands.

The sheath losses can be reduced, if necessary by installing auxiliary copper conductors in close proximity of the cables to provide a low resistance secondary winding.

(iv) *Cable sheaths as return paths for fault current.*—One of the most important subsidiary functions of the cable sheath is to provide a low impedance path for fault current to return to the system neutral. For this purpose, it is necessary that the sheaths should be effectively bonded together and earthed at both ends. The arrangement of the cables

in close triangular formation, with their sheaths bonded and earthed, is seen to minimise sheath losses and eliminate induced voltages and is also satisfactory as an earth fault current return circuit.

(v) *General recommendations.*—(1) Single core cables should be laid in close triangular formation, the sheaths being bonded together and earthed at both ends and on long runs in racks at intermediate points also. The sheath losses should be calculated for each installation to ensure that they are not excessive.

(2) When it is necessary to depart from the close triangular formation for termination or other purposes, the spacing between cable and the length of the separated section should be kept as small as possible.

The sheath losses should be calculated and if the losses are tolerable, the glands should not be insulated. Consideration should be given, if necessary, to the reduction of the losses by means of auxiliary copper conductors. Other things being equal, preference should be given to earthed glands.

(3) Care should be taken to ensure that the cable sheaths are in such a way as to provide an adequate and low impedance circuit for earth fault currents.

(vi) *Bonding and earthing of cable sheaths-II.*—(1) The introduction of sheath insulating joints to break up the voltage generated in long runs of cables is not considered a satisfactory practice in the BEA. In BEA practice, this is best accomplished by bonding across the 3 single core cable sheaths at frequent intervals.

(2) The limit of 10 to 15 volts sheath voltage is high as it would mean no more than 5 bonds or breaks per mile. BEA always specify bonds at the end of each drum length and where joints occur, and prefer to have intermediate bonds as well. Probably it is better to state a bonding distance of say 50 yards irrespective of the size of the cable for the voltages induced on short circuits have an important bearing on this. Even 15 volts may cause sparking on accidental vibrating contact to a metal bar lying across bare parts of the sheath and there might be actual burning on short circuit.

(3) The sheath current loss increases with decrease of the resistance of the paths within the range of the numerical ratios involved when the cables are grouped in triformation but frequent bonds will not increase the loss significantly.

(4) When the three cables are fanned out wide apart, the condition of (3) reverses and there is substantial reduction of sheath loss if the sheath currents are given lower resistance paths. BEA advocated the use of the auxiliary copper conductors about ten years ago for that same reason. In most cases, there is no need for a very elaborate arrangement. There should always be a substantial earthed bonding at the breech, where the cables fan out, and another cross bond near the sealing ends. Copper strips run along each cable and joints to these bonds at each end should be added only if the cable current loads are very heavy.

6.9. *Operating practice*—(i) *Load shedding in the event of exceptionally serious breakdown on the grid system.*—Under normal conditions, instructions regarding load shedding will be issued to the generating stations by the Control Engineer, but in the event of exceptionally serious breakdown, part or parts of the grid system become disconnected and temporarily out of control. If insufficient generating plant is available to meet the load in an isolated section, a rapid fall of frequency below the normally possible minimum of 48 cycles per second may occur in that region.

In this event the following action should be taken at each generating station in the affected section or sections without waiting for instructions from the Control Engineers :—

(*a*) The output of the station should be increased to and maintained at the highest level possible.

(b) When the frequency falls to 47·5 cycles per second and if the indication is that it is likely to fall still further, 20 per cent of the load supplied from the station bus-bars should be shed.

(c) If the frequency continues to fall further, cuts of 20 per cent should be made as may be necessary to prevent the frequency falling below 46 cycles per second.

(ii) *Frequency and time control.*—Both under normal conditions and when any regrouping of areas takes place National Control shall be responsible for co-ordinating arrangements for controlling frequency and electric time. Except in special circumstances the permissible variation from normal shall be as follows ;—

Frequency ± 0·1 cycle.

Electric time ± 5 seconds.

The target frequency shall be 50 cycles. If the frequency departs from 50 cycles the total area output shall be increased or decreased by an agreed percentage of 0·05 per cent for each 0·1 cycle by which the system frequency is below or above the target frequency respectively, up to the limits of transmission capacity. In addition National Control may direct more areas to adjust their generation without further instructions by an agreed amount whenever the frequency varies by 0·4 cycle per second from the target frequency. When high frequencies are necessary for correction of electric time the national frequency must not exceed the upper limit laid down from time to time.

(iii) *Method of determining overall M.C.R. heat rates of generating sets and performance factors of generating stations—(Central Electricity Board—Operation Memorandum).*—A standard method of assessing overall M.C.R. heat consumptions of generating sets is required in order to determine more accurately the relative fuel costs of generating plant in the country for the purpose of planning economic loading programme. An indication of the variations in the performance of each station compared with some target will also be useful and a method based on certain approximations and suitable for application to all stations has been developed to give the required information as simply as possible and is described below.

Briefly, it is proposed that the minimum total heat required by the generating sets in a station to carry out a given programme of generation should be calculated each month and compared with the heat actually consumed by the station (excluding banking) in meeting this programme. The ratio of these two quantities provides a factor which when applied to the basic M.C.R. heat consumption per unit of each set at T.S.V. will give the overall heat input to the station required in practice for each unit generated by that set at M.C.R. This figure will be known as the overall M.C.R. heat rate for the set.

The station performance factor is derived by calculating the minimum total heat consumption required by the station as a whole for meeting a given programme assuming an optimum boiler efficiency, and adding to this figure, the amount of heat required for banking purposes and comparing the resultant figure with the total heat consumed by the station during the period under review.

The two sections of dual pressure stations should wherever possible be treated as two separate stations and performance factors should be calculated for each section.

Description of procedure.—(1) The minimum heat consumption of the generating sets in each station is calculated from the actual running hours and units generated by each set including house service set and employs simplified Willans lines as described in paragraph (iv)below. It will be seen that, once certain basic data have been established for

each set, the minimum heat required by that set to carry out a specified programme of generation may be quickly determined and the minimum total heat required by all the turbine plant in a stations during a month's operation is readily obtained.

(2) The actual heat consumption of the station during running periods is obtained by deducting from the total heat consumption of the station, the heat consumption during offload periods. The proposed basis for assessing the heat consumption during offload period is described in paragraph (v) below. This may include an adjustment for depreciation of coal in stock.

(3) *Overall M.C.R heat rate of each set.*—The ratio (2)/(1) when applied to the M.C.R. heat rate of each set gives the overall heat rate to be used for operational purposes after adjusting to a sent-out basis. In cases where it is known that the specified minimum heat consumption of a particular set cannot at present be approached in practice due to some temporary cause, such as exceptionally bad condition or temporary removal of blading, an agreed further adjustment may be applied so that the heat rate used for operational purposes shall be as nearly as possible correct relative to the other sets in the station. Such an adjustment is to be applied only in connexion with the calculation of the overall heat rates of the sets and should not be taken into account in arriving at the minimum heat consumption for the calculation of the performance factor unless the modification is of a permanent nature.

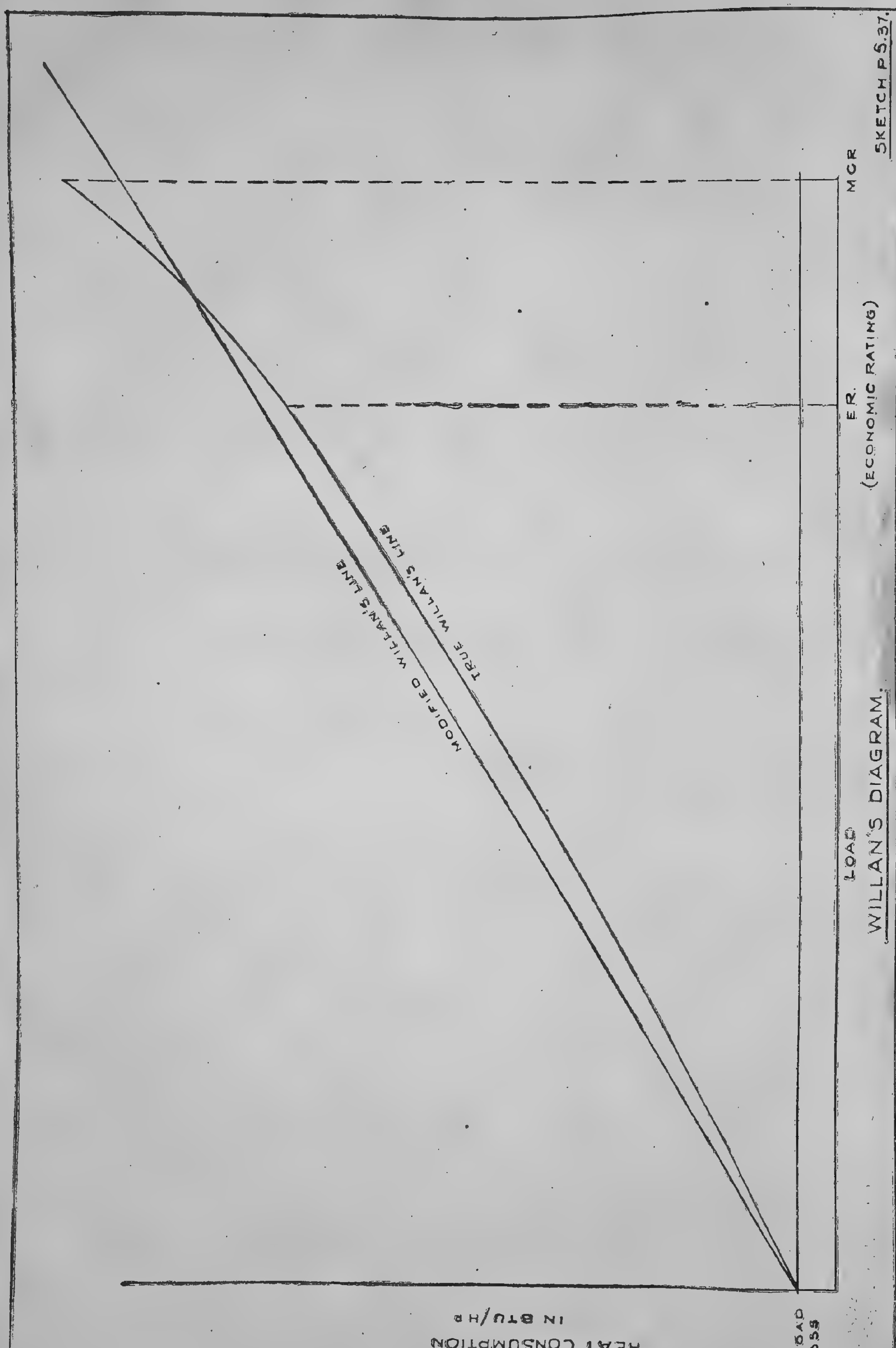
(4) *The performance factor of the station* is the ratio of the calculated overall minimum heat requirements of the station, assuming optimum boiler efficiency (Para vii) and including an allowance for offload heat consumption (paragraph v) to the total heat actually consumed at the station during the period under review.

(iv) *Method of determining the minimum heat consumption of turbines.*—The calculation of the minimum heat requirements of a turbine to carry out a given programme of generation is derived from a modified form of Willans line. To construct this line, it is necessary to know for each set, the heat consumptions including feed heating and any steam auxiliaries normally in continuous use, at M.C.R., E.R. and some lower loading preferably no-load. These figures should represent the consumption under optimum conditions and should for preference be the figures obtained during the acceptance tests, when the plant was first put into operation. The construction of the modified Willans line is shown in Sketch P.S. 37.

It will be seen that the modified Willans line joins the no load heat consumption to a point on the true Willans line, approximately midway between E.R. and M.C.R. consumption. The deviation from the true Willans line will be small in a majority of cases. The total heat requirements of the set consist of the 'no-load' consumption which is dependent on the hours run and the incremental consumption which varies with the units generated. The former is a product of the no load heat consumption per hour and the running hours of the set and the latter is obtained by multiplying the units generated by the additional heat required to generate each unit.

As an example if the economic rating of a set is 80 per cent of the M.C.R. rating and the true heat consumption at E.R. and M.C.R. are 11,800 and 12,000 B.T.U./unit generated respectively, the heat consumption per unit generated at 90 per cent M.C.R. is to be taken as $\left(\frac{11{,}800+12{,}000}{2}\right)$ or 11,900 B.T.U. If the set concerned is a 30 MW. machine, and no-load loss is 6 per cent of the total heat consumption at M.C.R. the derived basic data will be as follows :—

(*a*) The no-load heat consumption per hour, $30{,}000 \times 12{,}000 \times \cdot 06 = 21\cdot 6$ million B.T.U.


SKETCH P.S.37.
MCR
E.R.
(ECONOMIC RATING)
TRUE WILLAN'S LINE
MODIFIED WILLAN'S LINE
LOAD
WILLAN'S DIAGRAM.
HEAT CONSUMPTION
IN BTU/HR
NO LOAD
LOSS

(b) At 90 per cent of M.C.R. the total heat consumption per hour will be 30,000 × 0·9 × 11,900 = 321·3 millions B.T.Us. Of this 21·6 million B.T.U/hr. is required to meet the no load loss of the set so that the generation of 27,000 units actually requires 299·7 million B.T.U. (i.e.) the additional heat consumption per unit generated is $\frac{299 \cdot 7}{27,000}$ or ·011 million B.T.Us.

If therefore this set ran for 602 hours in a month and generated 15 million units, the minimum heat requirements of the set are given by—

No load consumption = 602 × 21·6 = 13,000 million B.T.U.
Heat required for generation = 15 × 10^6 × ·011 = 166,500 million B.T.U.

179,500 million B.T.U.

(v) *Determination of station heat consumption during offload periods.*—The 'offload' heat consumption is intended to include all heat supplied to the boilers at all times when the boilers are not actually supplying steam for the direct purpose of generation and therefore includes all heat used in maintaining the boilers in a banked condition, in bringing up banked boilers to pressure and in bringing the boilers on to the range from cold.

For pulverised fuel, and oil fired boilers and in those cases where chain grate boilers are burned off and boxed up, the fuel consumed during offload period is that required to restore the steam conditions to normal.

Banked boilers.—From a detailed examination of the fuel consumption required for boiler banking at a number of stations, typical figures for the banking consumption have been derived. These figures represent the average consumption per hour during the banked period and include an allowance for the heat required to raise the boiler pressure to normal, before the boiler is put back on the range. The allowances to be adopted are 0·42 million B.T.U./hr. for 10,000 lb./hr. of boiler capacity in the case of boilers installed in 1938 or later and 0·7 for older boilers. For pulverised fuel and oil fired, the allowance is 0·42 million B.T.U./hr. for 10,000 lb./hr. of boiler capacity irrespective of the date of installation.

Examples of the offload consumption under different circumstances are given below :—

Chain grate boilers 150,000 lb./hr. capacity installed in 1942.
Total boiler banking hours say 350.
Total offload heat consumption, 15 × 350 × 0·42 = 2,205 million B.T.U.
Pulverised fuel in oil fired boilers 120,000 lb./hr. capacity installed in 1936.
Total boiler banking hours, 520.
Total off-load heat consumption, 12 × 520 × ·42 = 2,620 million B.T.U.

(vi) *Starting up boilers from cold.*—The following standard allowances should be used in calculating the heat associated with the starting up of cold boilers.

Capacity K.lb./hr.	Assumed heat requirements in million B.T.U.	Capacity K.lb./hr.	Assumed heat requirements in million B.T.U.
20	19·0	75	71·4
30	28·4	80	75·6
40	38·0	100	95·2
50	47·5	120	114·0
60	58·0	150	143·0

(vii) *Optimum boiler efficiency.*—The optimum boiler efficiency to be used in the determination of the performance factor should be the efficiency of the boiler when steaming at economic loading, burning the class of coal for which it is designed and operating under 'as new' conditions.

In calculating the efficiency the gross calorific value of the fuel should be used and the boiler should be debited with the heat consumption of any steam auxiliaries which are normally in continuous use for steam raising.

6.10. *Operating personnel and costs.*—The operating and maintenance personnel in the B.E.A. averages one man per mega watt of power generated by steam. In 1951 the operating cost was 5*d* per unit while the cost of fuel and fuel handling was 0·734*d*.

6.11. *Inspection and overhauls*—(i) *Boiler Inspection.*—There is a British legislation requiring an extremely thorough boiler inspection by an outside inspector every 14 months for rivetted drum boilers and 18 months for welded drum boilers. The present method requires a thorough cleaning of tubes by brushing and lancing and the interior of drums must be scrapped. This usually takes one week using quite a number of men. The inspector also requires one week to complete his work, so that two full weeks are required for the preparation and inspection of a boiler. Two weeks time in every 14—18 months in the life of the boiler would mean 3·8 per cent of the boiler equipment out of service in its life time.

In American practice the insurance inspection is made once a year, but at a time convenient to the utility and without any lengthy preparation. It is usually done over week ends. Insurance inspection is done during short overhaul periods which may occur once a year or a year and a half. A hydrostatic test at $1\frac{1}{2}$ times the working pressure is also made once a year.

(ii) *Periodical Inspection and cleaning.*—In the United Kingdom, a general survey of boiler pressure parts and an overhaul of fittings is necessary to comply with the regulations of the Factories Act. On these occasions, the operating Engineer should make a thorough inspection both before and after any hand cleaning or maintenance work is carried out, looking particularly for evidence of internal or external corrosion, soot blower erosion, leakage, overheating or structural deterioration.

If possible a new boiler unit should be inspected externally at least twice during the first year and as often as possible during the first few months of steaming. Only the minimum amount of cleaning of refractory faced surfaces should be carried out.

Any pitting or other corrosion found should be scraped, and cleaned with a wire brush, until the metal is perfectly clean. Any boiler tube joints showing signs of having leaked out should be carefully expanded.

The most satisfactory method of removing bonded deposit from the gas side of economisers and air heaters is now recognised to be water washing. When the design of a plant does not permit washing water to be led away, it is worthwhile fitting temporary baffles and ducting so that this method of cleaning may be employed. It may be necessary to wet the deposit first with an alkaline solution to neutralise any acid and the heating surfaces should then be thoroughly washed with a hose. It is essential to dry off quickly afterwards to avoid corrosion and this can be achieved by commencing the cleaning operation as soon as possible after the unit is shut down.

(iii) *Inspection and overhauls.*—The present British practice for major plant overhauls and inspection is about four to six weeks each year for boilers and about six to eight weeks in alternate years for turbo alternators. In the United States of America the overhaul practice is about fourteen days for boilers each year and twenty-four days for turbo alternators every third year. The annual inspection of boilers is governed by legislation in both countries.

(iv) *Overhauls.*—The period between turbine overhauls in Britain is three years. In America with the practices of Magniflexing the blades, by careful alignment checks, by the use of thermo-couples in thrust bearings, by close checks on stage pressure and vibration records, it is possible to increase the time between overhauls in some systems to four and even six years.

7. Sweden.

7.1. HARSPRANGET POWER STATION.

Harspranget is situated about 40 kilo meters within the arctic circle. The power plant is the second within a projected series of seven that will be built on the river between lake Lulejaure and the gulf of Bothinia.

The water flow of the river is effectively regulated by means of a large storage reservoir at Suorva of a capacity of approximately 2,750 million cubic metres.

The construction was started in 1945 and completed in 1952. This is the largest power station built in Sweden the output of which amounts to about 10 per cent of the total output of water power produced at present, in the country.

The details of the water flow and catchment area are as follows :—

Catchment area above Harspranget—10,000 sq. kilo metres.

Exceptional high water flow—1,200 cubic metres/sec.

Normal—670 cubic metres/sec.

Mean flow—255 cubic metres/sec.

Water flow in normal year (winter)—250 cubic metres/sec.

Water flow in normal year (dry)—210 cubic metres/sec.

The generator floor is located 76 metres below ground level.

Maximum turbine discharge—400 cubic metres/sec.

Upstream water level—311·5 metres.

Down stream water level—205·0 metres.

Gross head—106·50 metres.

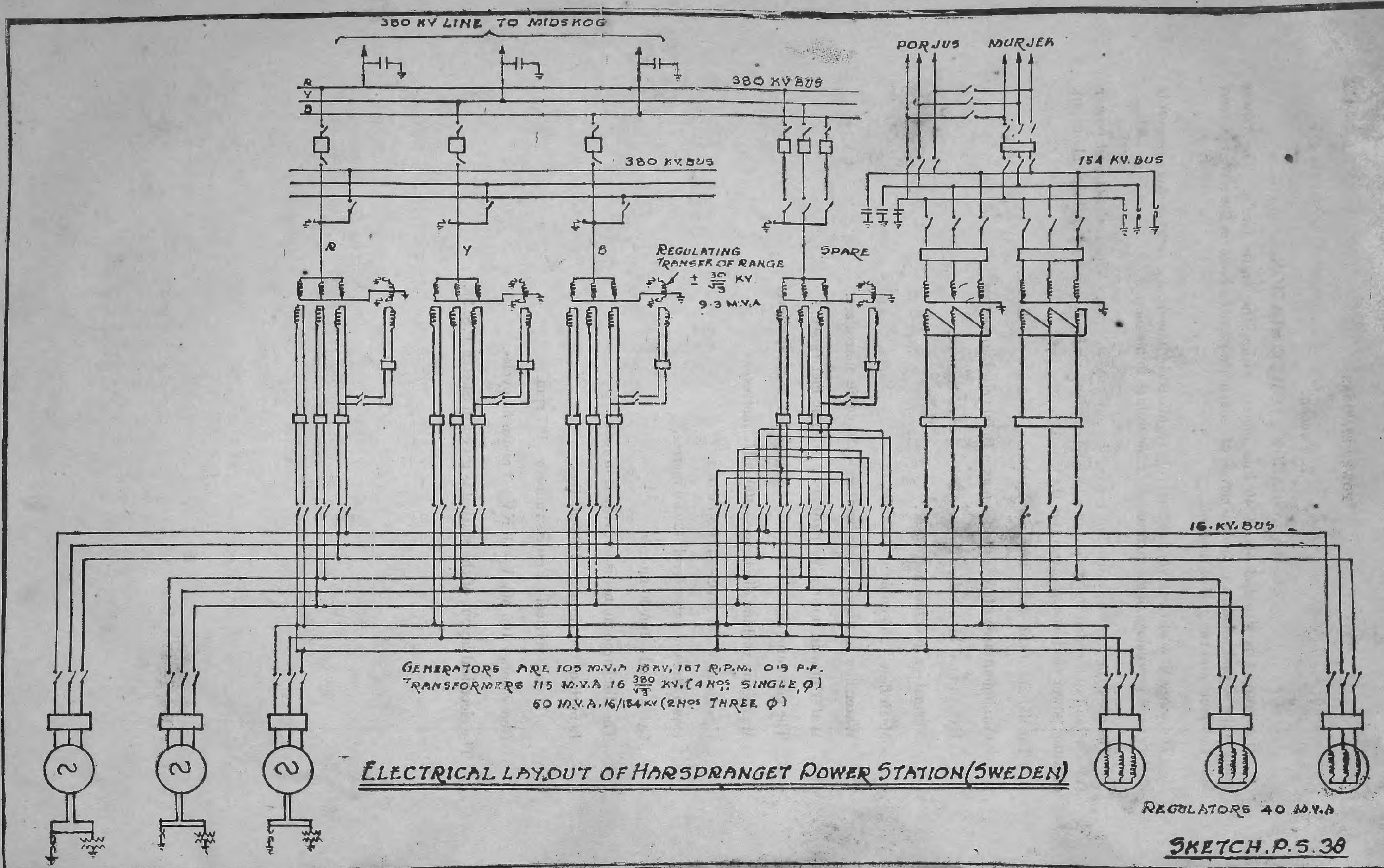
The discharge tunnel is excavated in rock.

Length of the tunnel—2,900 metres.

Turbines—vertical—Francis runners—167 rpm.

Generators—105 MVA—16 KV—3 phase 50 cycles.

The electrical layout of the station is given in Sketch P.S. 38.



ELECTRICAL LAYOUT OF HARSPRANGET POWER STATION (SWEDEN)

SKETCH. P.S. 38

TABLE 7.—7.2. *Data for Generators and Transformers.*

Sweden.

Station.	Generator Data.									Transformer Data.		
	MVA *P.*	*KV*	*Subtransient reactance.* PER CENT.	*Transient reactance.* PER CENT.	*R.P.M.*	*GD²* *ton M².*	*W* *MW × secs.*	$\left[\frac{W}{P}\right]$ *secs.* *H.*	*Syn. Reactance.*	*M.V.A.*	*KV/KV Ratio of Transformer.*	*Reactance.* PER CENT.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Porjus G. 250	20	7	28·5	..	231	ca 1,130	82·5	4·13	73	....	....	....
Do. G. 550	17	7	23·3	ca 25	250	ca 1,110	95	5·59	70	....	....	....
Do. G. 650 O.	9	6·6	18	ca 20	250	634	54·3	6·03	ca 89	....	....	....
Do. G. 750	..	..	..	..	..	..	..	..	..	....	....	....
Do. G. 850	28	7	24·4	..	214	1,550	97	3·46	71	....	....	....
Harspranget	3 × 105	ca 16	19	24	167	10,250	..	5·3	65	3 × 105	15/260	8
Norrfors	2 × 12·5	6·6	27·5	ca 30	187	740	35·4	2·83	98	....	....	....
Hissmofors	3 ×	..	..	..	..	..	..	..	..	....	....	....
Kattstrupeforsen	2 × 20	11	25	..	125	2,500	53·5	2·67	69·5	....	....	....
Midskog	2 × 55	11·8	25	ca 28	136·3	6,857	175	3·18	74	2 × 55	230/11 ; 1 ; 11·8	12·7 a 12·4
Stadsforsen	2 × 40	9·8	27·8	..	125	4,570	98	2·45	83·3	2 × 40	230/9·8 ; 9·3	12·5 a 12·7
Holleforsen	3 × 55	9·8	19	..	125	9,360	..	3·6	..	3 × 55	9·8/230	8
Sillre	2 × 7	7	22·7	ca 25	600	25	12·3	1·76	78·7	....	....	....
Namforsen	28	11·8	26	ca 30	136	3,100	78·5	2·80	74	56	11·8/230	8
Forsmo	45	11	18·6	21·7	167	4,900	187	4·16	77	45	11/230	8
Torpshammar	52·5	11·0	22·2	ca 25	250	2,000	172	3·27	69	62·5/10/52·5	230/40/10·3 ; 11·0	11/230 KV, 12·0 (1)
Leringsforsen	10	6	21·8	..	167	840	32	3·2	71·5	....	....	....
Alvkarleby	5 × 15	11	..	..	150	3,600	115·3	7·7	64	....	....	....
Motala	3 × 6	7	13·4	..	167	275	10·05	1·75	110	....	....	....
Molfors	2 × 14	6·3–7·0	..	..	167	668	..	..	..	20	7·4/132	....
Trollhattam G 2	11	11	..	..	..	..	..	..	..	....	....	....
Do. G 6	14	10–11	20	..	187·5	1,000	48·2	3·44	91	....	....	....
Do. G 7	11	10–11	..	..	187·5	990	47·7	4·33	47	....	....	....
Do. G 8	14	11	21·7	..	187·5	ca 950	45·7	3·26	94	....	....	....
Do. G 9	14	11	..	..	187·5	880	42	3·0	79	....	....	....
Do. G 10	11	11	..	..	..	..	..	..	..	....	....	....
Do. G 11 D ..	16·5	10–11	..	..	187·5	1,876	90	5·45	..	....	....	....
Do. G 12 D o G 13 D	11	11	..	..	187·5	1,594	76·8	6·88	72	....	....	....
Hojum (G. 14 o. G 15) ..	52	11·3	25·6	ca 29	136·3	6,810	174	3·34	83·3	2 × 60	132/10·8	9·6
Vargon	12	10·5–11	25	..	46·9	12,500	37·6	3·13	91	....	....	....
Lilla Edet	12·5	11	..	..	62·5	..	..	..	..	....	....	....

TABLE 7.—7.2. *Data for Generators and Transformers.*—cont.

Sweden.

Station.	Generator Data. P.	KV	Subtransient reactance. PER CENT.	Transient reactance. PER CENT.	R.P.M.	GD_2 ton M_2	W MW × secs.	$\left[\frac{W}{P}\right]$ secs H.	Syn. reactance.	Transformer Data. M.V.A.	KV/KV Ratio of Transformer.	Reactance. PER CENT.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Vasteras G 5	50	7	..	..	1,500	..	..	..	..	....	....	....
Do. G 2	30	7	..	..	3,000	..	..	..	..	....	....	....
Finnslatten	..	..	..	..	..	..	..	..	..	3 × 60	205/74/9·8	12·0 + (0·55 a 0·8)
Hallsberg	..	..	..	..	..	..	..	..	..	(120)	205/132	11·1 + (1·3 a 2·4)
										(120)	205/132	11·0 + (1·3 a 2·4)
Morsil	2× 22	9·5–10·5	17·5	21	136	3,500	..	..	83	43	9·5/220	10
Jarpstrommen	3 × 40	16·5	26·5	..	167	(3 × 4,400) (	3×168)	4·2	59	3 × 40	16/232	11
Krangede	6× 35	8·4	17	20	167	4,720	180	5·15	59	35	8·5/220	17·0
Gammelange	2 × 25	9·5	22	25	125	4,000	85·2	3·4	62	25	9·5/220	13·2
Hjalta	2 × 65	14·0	22	25	187·3	5,300	255	3·9	71	65	14/230	8
Hammarforsen	2 × 12	6	24	27	94	2,750	34	2·84	94	2 × 12	6·3/77 ± 5 per cent.	9·4
Do.	2 × 18	8·5	25	29	150	2,020	62	3·44	95	2 × 18	8·5/132 ± 5 + 10 per cent.	8·3
Horndal	..	..	..	..	..	..	..	..	..	30	205/80/10·25	205/80 15 per cent. 205/10·25 16·5 per cent. 80/10·25 4·5 per cent.
Do.	..	..	..	..	..	..	..	..	..	30	80 ± 4 × 2	0·95—1·1
Granlo	..	..	..	..	..	..	..	..	..	2 × 16·5	120/77 ± 5 ± 10 per cent.	9·2
Do.	..	..	..	..	..	..	..	..	..	45	Do.	10·5
Ange	..	..	..	..	..	..	..	..	..	22	210/77	11·5
Do.	..	..	..	..	..	..	..	..	..	22	77/62—92	1·7—0·5
Untra—42 }	60	7·5	..	..	125	..	..	..	..			
Lanforsen—18 }		6·6	12·5	..	93·6	9,460	163	2·7	69	37/50/50	7·5/105/220	....
Vartan	100	6·6	11·5	..	1,500—3,000	..	..	..	100	2 × 125/60/125	200/100/30 ± 7 × 0·5	14·7, 9·1
Skanstull	..	..	..	..	..	..	..	..	..	100	200/30	16
Karsefors	19	6·3	24·5	..	125	2,600	55	2·9	85·5	2 × 21	132/6·3	14·4
Laholm	12	6·3	18·2	..	83·3	4,560	43	3·58	91·5	12	132/6·3	11·6
Malmo	35	5·25	16	..	3,000	11·15	137	3·9	140	2 × 35	55/5·5	9·5
	12	5·25	25	..	750	..	..	..	165	2 × 12	51·5/5·6	8·5
Traryd	8·5	6·3	18·2	..	187·5	440	21·1	2·5	84·5	17	132/6·25	8·4
Skogaby	5·0	5·5	..	..	167	340	12·9	2·6	78·5	3 × 5	54/5·05	6·5
Nassjo	..	..	..	..	..	..	..	..	..	2 × 50	200/142—116	11 + (1·0 a 1·6)
Sege	..	..	..	..	..	..	..	..	..	90	132/65—50	11·6—11·0
Knard	..	..	..	..	..	..	..	..	..	30	132/52·5	11·2

Reactance based on 52·5 MVA